

Ogden Air Logistics Center



Low Hydrogen Embrittlement (LHE) Zn-Ni Plating Qualification and Implementation on Landing Gear Components

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U.S. AIR FORCE

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LHE Zn-Ni Partners



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Agenda



- **Required Qualification Testing**
- **Questions/Answers of Original Phase II Fatigue Testing**
- **Additional Testing**
- **Specifications and Source Control Drawings**
- **Prototype Plating Line**
- **Component Corrosion Evaluation**
- **Performance Tracking Program**
- **Implementation of Large Scale Prototype LHE Zn-Ni Plating Line**



Required Qualification Testing (Passed)



- Adhesion (ASTM B571) (Passed)
- Hydrogen Embrittlement (ASTM F519) (Passed)
- Re-embrittlement (ASTM F519 & USAF DWG 9825019) (All Failed)
- Liquid and Solid Metal Embrittlement (ASTM F519) (Passed)
- Fatigue (ASTM E466) (Passed)
- Corrosion (ASTM B117) (Passed)
- SO₂ Corrosion (ASTM G 85) (Did as well as Cadmium)
- Brush Plating for Repair of Damage LHE Zn-Ni Platings (Touch Up) (ASTM B117, ASTM B571 and ASTM F519) (Passed)
- Installation of small tank LHE Zn-Ni Prototype Line





Phase II Fatigue Testing



- Fatigue test were performed to evaluate the service life impacts associated with platings
- Questions regarding the fatigue test program and interpretation of existing results to sufficiently characterize the service life impacts associated with LHE Zn-Ni plating in lieu of Cadmium plating were raised
- 417 SCMS/GUEA Landing Gear Engineering Branch engaged the Landing Gear Design Industry to determine if the fatigue testing and test results per the following fatigue testing matrixes is adequate to approve the use of LHE Zn-Ni on HSS landing gear components



Phase II Fatigue Testing

- All fatigue test data was included in the statistical analysis
- A conservative approach was taken plating the Zn-Ni fatigue coupons:
 - All Zn-Ni fatigue coupons were plated thicker than cadmium fatigue coupons (typical thickness 0.0002 - 0.0006 inches)
 - The nickel content for Dipsol Zn-Ni IZ-C17+ was at the upper limit (18%) of the USAF 201027456 plating specification drawing

Average Plating Thickness	(Inches)
Cadmium	0.00044
Dipsol Zn-Ni Tri CC	0.00091
Dipsol Zn-Ni Hex CC	0.00104
Atotech Zn-Ni Tri CC	0.00089
Atotect Zn-Ni Hex CC	0.00081



Phase II Fatigue Testing



- **Boeing Commercial (SDT) group evaluated the LHE Zn-Ni fatigue data and saw nothing that would alter their conclusion of the acceptability of the use of LHE Zn-Ni on high strength steel landing gear components**
 - **Boeing Commercial has approved Atotech® LHE Zn-Ni for high strength steel and is currently installing a LHE plating line**
 - **Structural Design Team stated that only one stress ratio is necessary and testing at different R ratios will yield the same result.**
- **Dr. Andrew Halfpenny a fatigue expert, from HBN, reviewed the fatigue data and determined that the LHE Zn-Ni is a suitable drop in replacement for cadmium**



Phase II Fatigue Testing



- **Heroux-Devtek stress group evaluated the LHE Zn-Ni fatigue data and concluded it is acceptable for use on high strength steel landing gear components**
 - **Heroux-Devtek has approved LHE Zn-Ni for high strength steel and is currently installing a LHE plating line**
 - **Stress group stated that only one stress ratio is necessary and testing at different R ratios will yield the same result.**
- **Boeing-Long Beach, structures group, would like to see additional testing (with more R ratios)**
 - **Currently working with Boeing-Long Beach conduct more fatigue testing per their direction**



Additional Testing



- **Corrosion Tests (Scribed Tests)**
- **Impact Tests (No further test information was required)**
- **Hydrogen Re-Embrittlement Tests**



Additional Corrosion Testing



- **Questions about the original LHE Zn-Ni and Cd corrosion panels scribe processing**
 - **It was determined that both types of panels were machined scribed**
 - **Many of the LHE Zn-Ni panels went over 5000 hours**
 - **Boeing machined scribed additional Zn-Ni and Cd panels and tested them per ASTM B117 for 1000 hours for a direct comparison**
 - **All the Zn-Ni plated panels passed the corrosion requirements called out in QQ-P-416 (no white corrosion products for 96 hours)**
 - **Results are shown in following slides below**



Additional Corrosion Testing



Table 1 - Machine vs. Carbide Scribed Corrosion Test

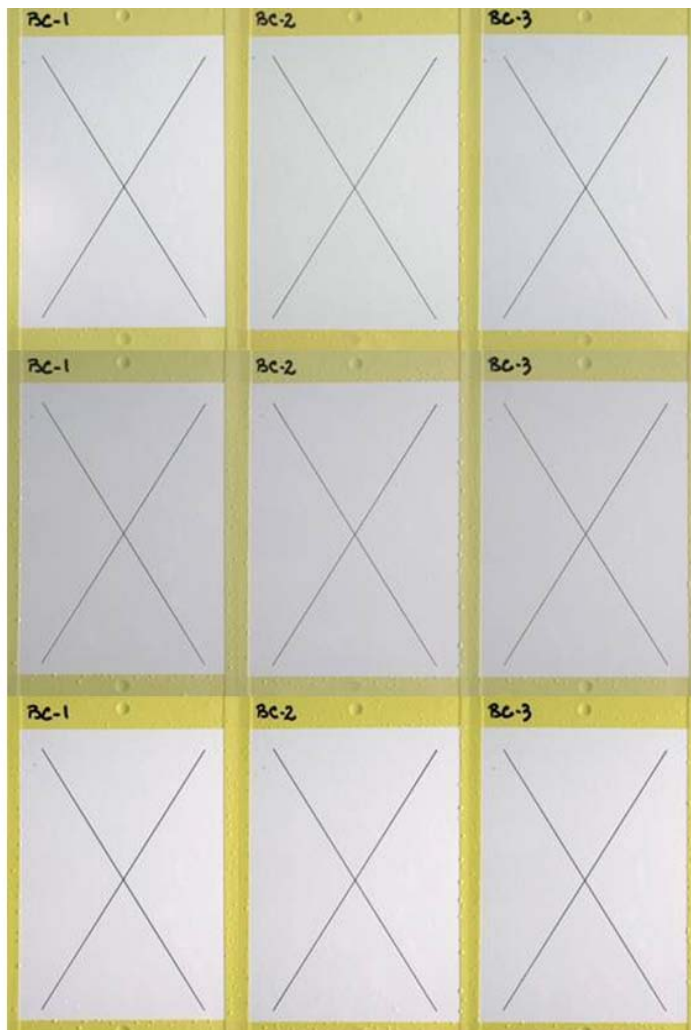
Group No.	Test Specimen* Identification	Plating Material	Conversion Coat Type	Plating Thickness (mils)	Primer + Topcoat	Type of Scribe	Test Duration**	Test Results
1	BC1	Zn-Ni	TriCr	0.6 +/- 0.15	Yes	Machined Scribe	1000 hrs	PASS
	BC2	Zn-Ni	TriCr	0.7 +/- 0.1	Yes	Machined Scribe	1000 hrs	PASS
	BC3	Zn-Ni	TriCr	0.7 +/- 0.1	Yes	Machined Scribe	1000 hrs	PASS
2	HC1	Zn-Ni	TriCr	0.8 +/- 0.2	Yes	Machined Scribe	1000 hrs	PASS
	HC2	Zn-Ni	TriCr	0.8 +/- 0.1	Yes	Machined Scribe	1000 hrs	PASS
	HC3	Zn-Ni	TriCr	0.8 +/- 0.2	Yes	Machined Scribe	1000 hrs	PASS
3	HC4	Cd	HexCr	0.8 +/- 0.05	Yes	Machined Scribe	1000 hrs	PASS
	HC5	Cd	HexCr	0.7 +/- 0.1	Yes	Machined Scribe	1000 hrs	PASS
	HC6	Cd	HexCr	0.5 +/- 0.1	Yes	Machined Scribe	1000 hrs	PASS
4	BS1	Zn-Ni	TriCr	0.8 +/- 0.05	No	Machined Scribe	1000 hrs	PASS
	BS2	Zn-Ni	TriCr	0.7 +/- 0.05	No	Machined Scribe	1000 hrs	PASS
	BS3	Zn-Ni	TriCr	0.8 +/- 0.05	No	Machined Scribe	1000 hrs	PASS
5	HS1	Zn-Ni	TriCr	0.8 +/- 0.1	No	Machined Scribe	1000 hrs	PASS
	HS2	Zn-Ni	TriCr	0.8 +/- 0.05	No	Machined Scribe	1000 hrs	PASS
	HS3	Zn-Ni	TriCr	0.8 +/- 0.1	No	Machined Scribe	1000 hrs	PASS
6	HS4	Cd	HexCr	0.8 +/- 0.1	No	Machined Scribe	1000 hrs	FAIL
	HS5	Cd	HexCr	0.7 +/- 0.1	No	Machined Scribe	1000 hrs	FAIL
	HS6	Cd	HexCr	0.8 +/- 0.1	No	Machined Scribe	1000 hrs	FAIL
7	BS4	Zn-Ni	None	0.8 +/- 0.1	No	Machined Scribe	1000 hrs	FAIL ****
	BN1	Zn-Ni	None	0.7 +/- 0.1	No	No Scribe	1000 hrs	PASS ****

**** Group 7 test coupons were run without conversion coating and were not required to pass (i.e. information only)

BR&T ASTM B 117 Corrosion Test Results



BR&T IZ-C17+ Zn-Ni w/Tri CC Scribed & Painted



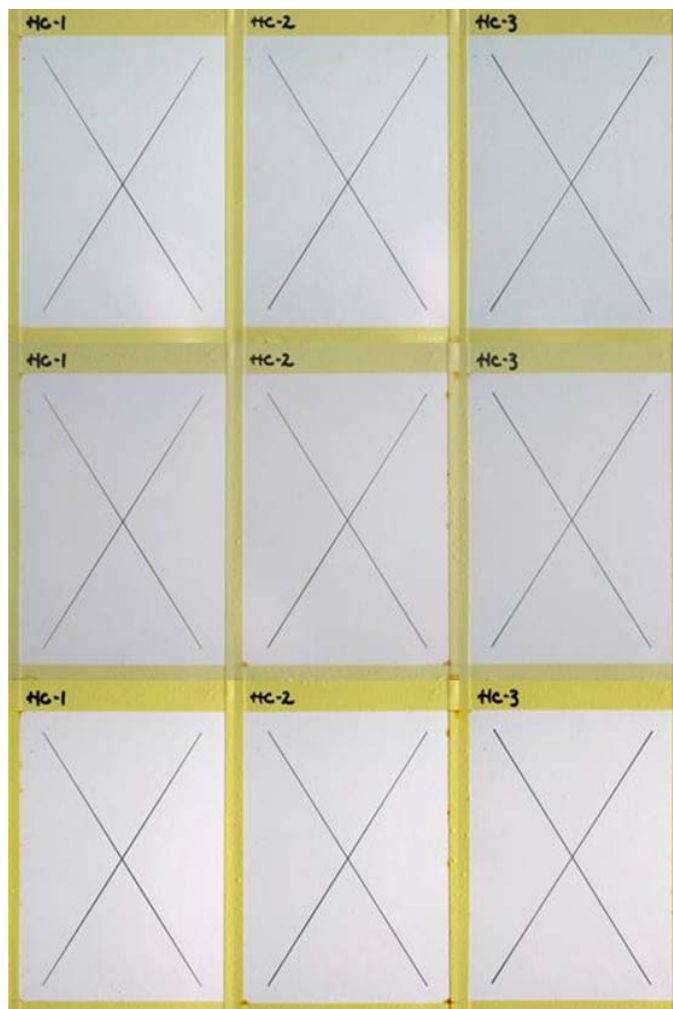
336 hours

672 hours

1000 hours



Hill AFB IZ-C17+ Zn-Ni w/Tri CC Scribed & Painted



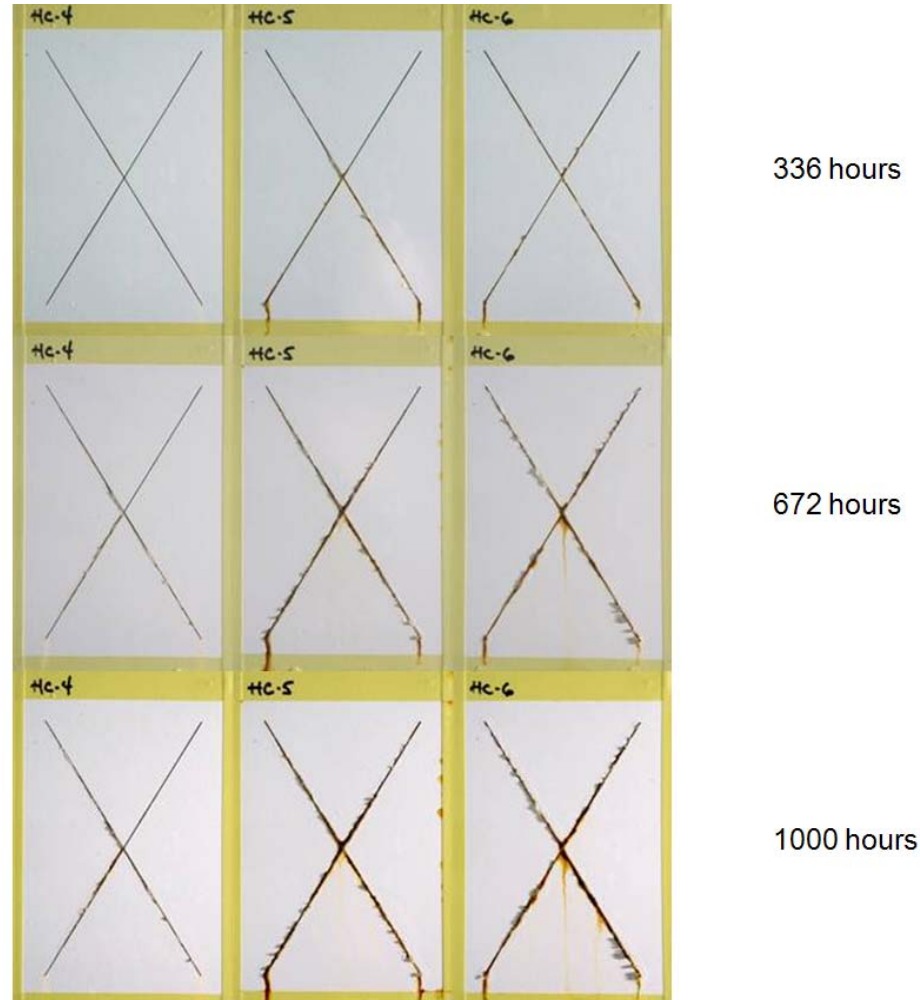
336 hours

672 hours

1000 hours

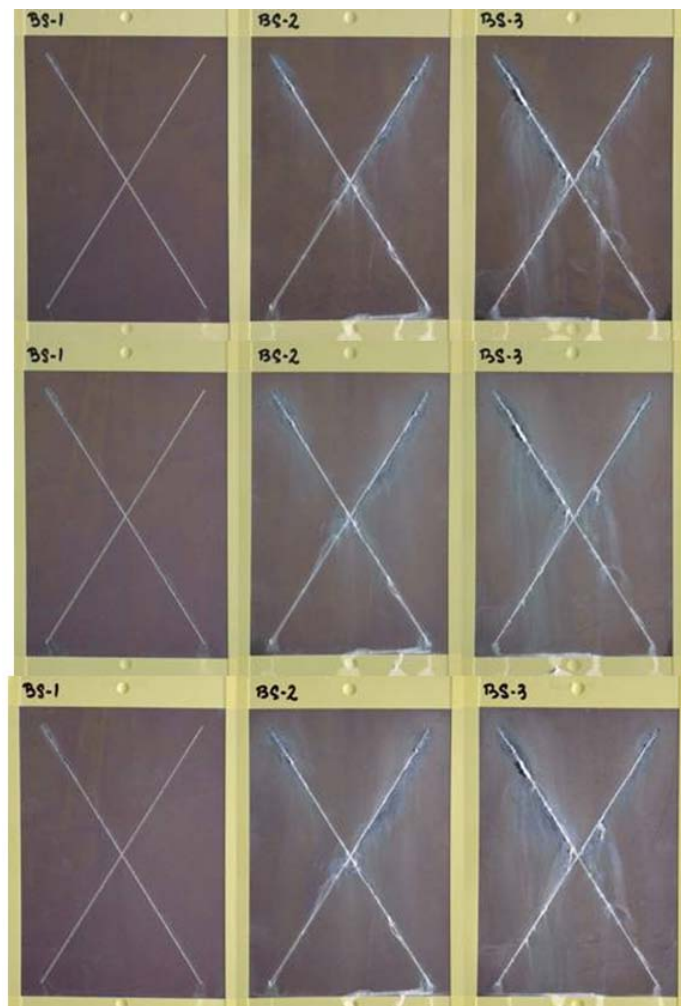


Hill AFB LHE Cd w/Hex CC Scribed & Painted





BR&T IZ-C17+ Zn-Ni w/Tri CC Scribed



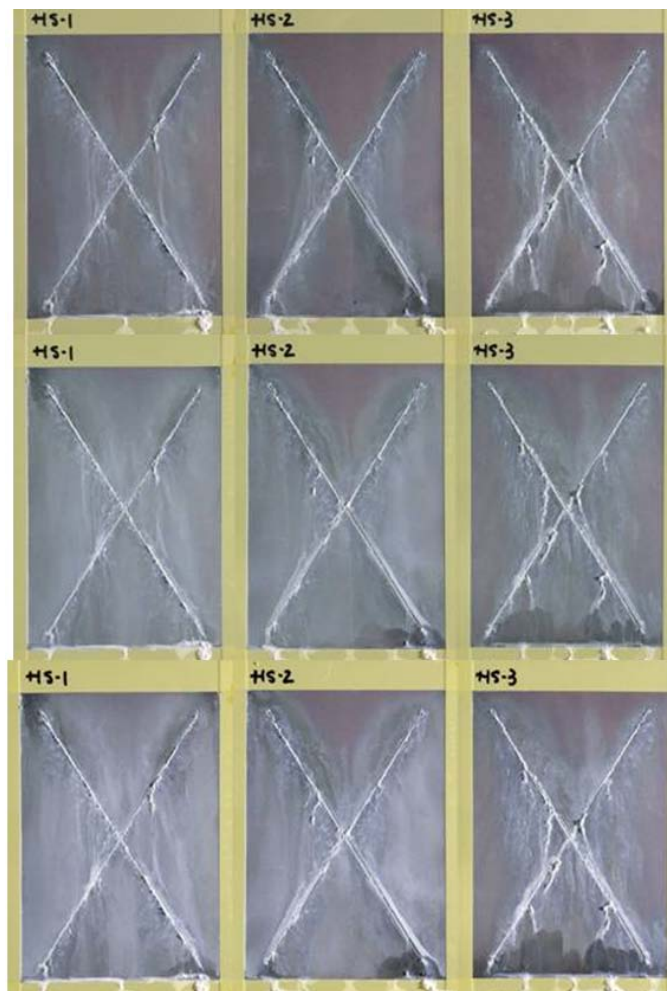
336 hours

672 hours

1000 hours



Hill AFB IZ-C17+ Zn-Ni w/Tri CC Scribed



336 hours

672 hours

1000 hours



Hill AFB LHE Cd w/Hex CC Scribed



336 hours

672 hours

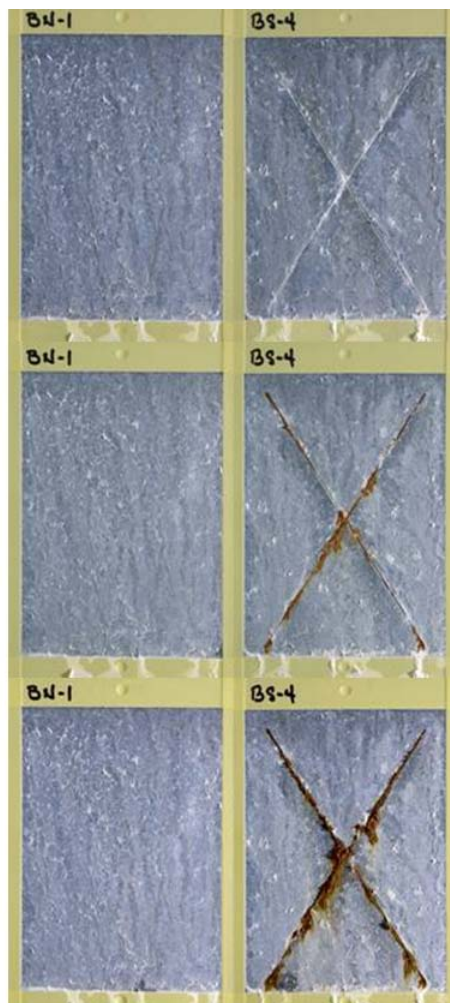
1000 hours



BR&T IZ-C17+ Zn-Ni w/ No CC Unscribed & Scribed



Group 7 test coupons
were run without
conversion coating and
were not required to
pass (i.e. information
only)



336 hours

672 hours

1000 hours



Additional Adhesion Testing

Gardner Impact Adhesion Tester





Additional Adhesion Testing

LHE Zn-Ni Adhesion Impact Test Result

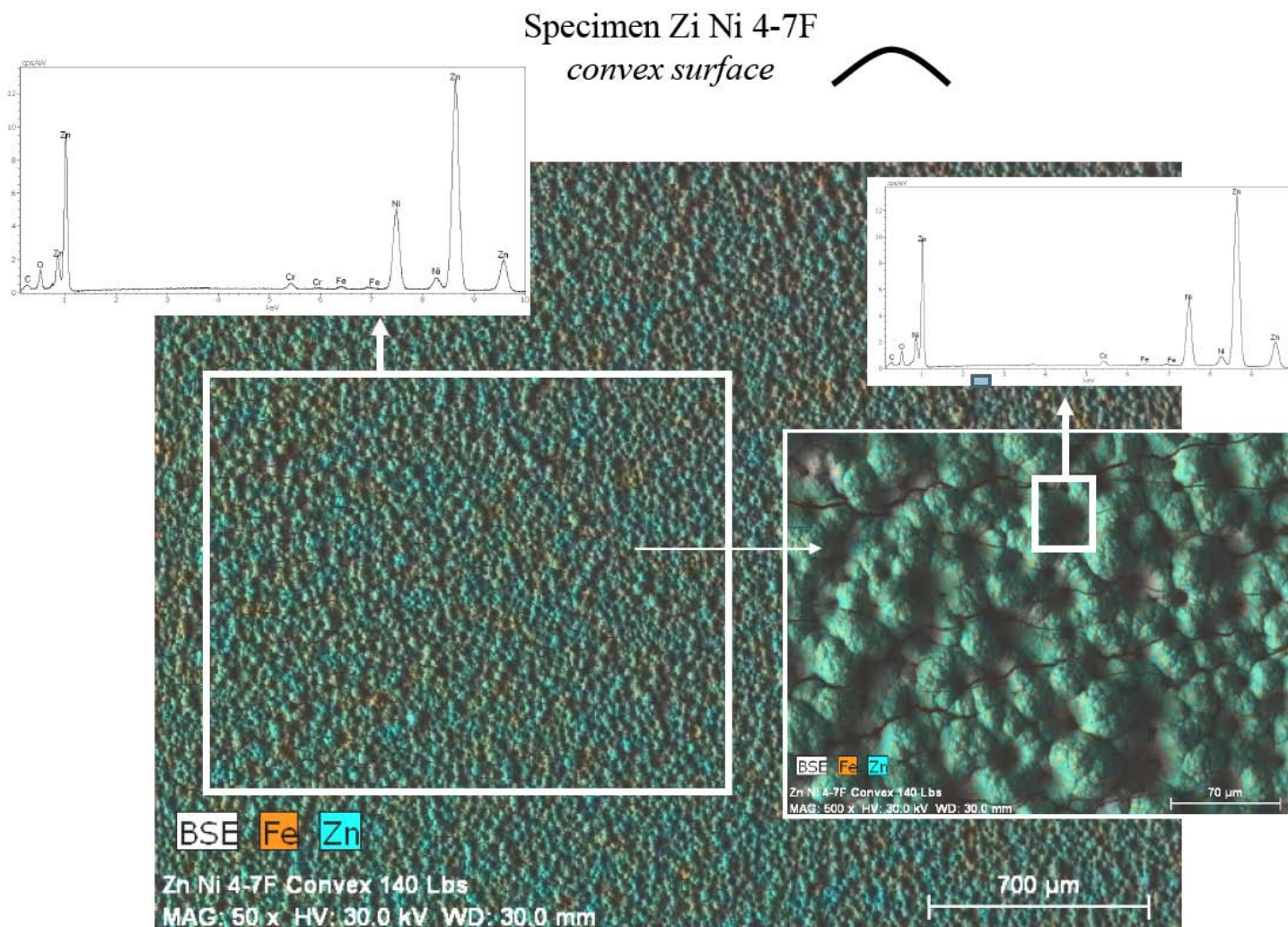


Impact at 70 in-lbs



Additional Adhesion Testing

Garner Impact Testing: Zn-Ni



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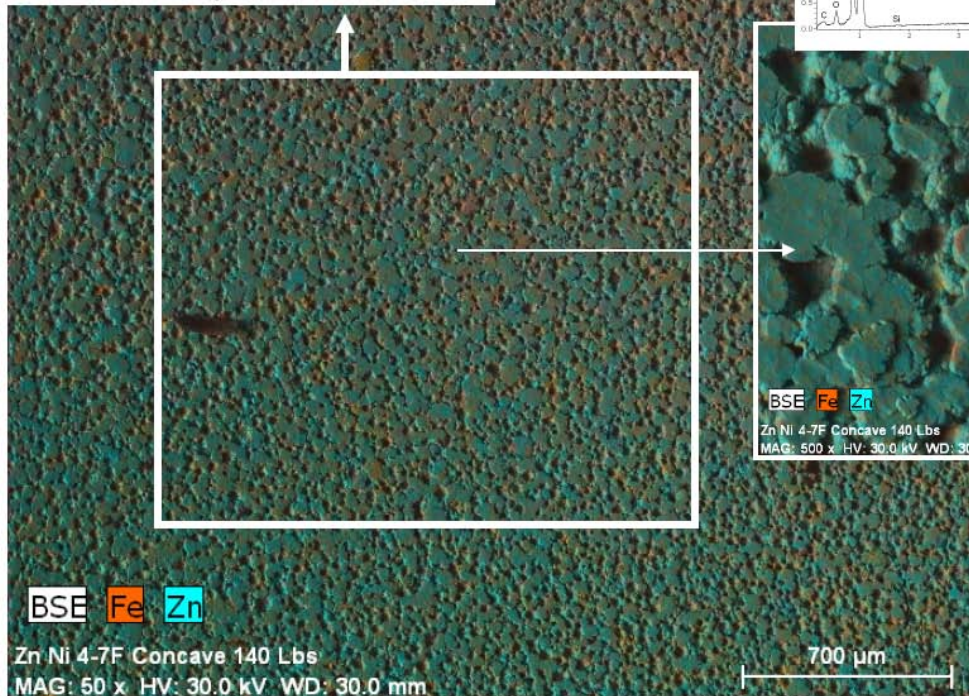
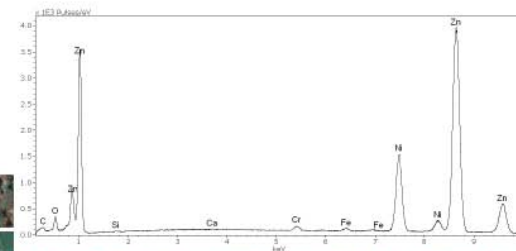
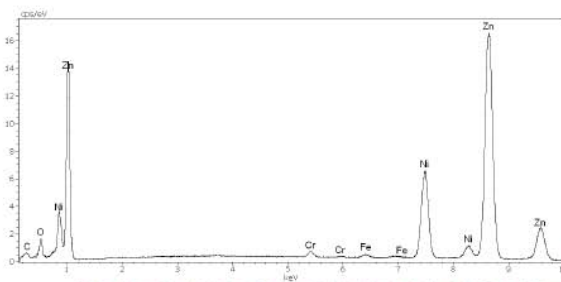
Additional Adhesion Testing

Garner Impact Testing: Zn-Ni



Specimen Zi Ni 4-7F

concave surface



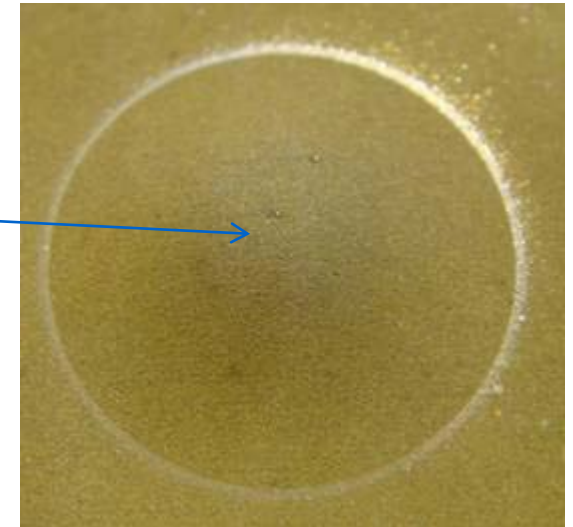
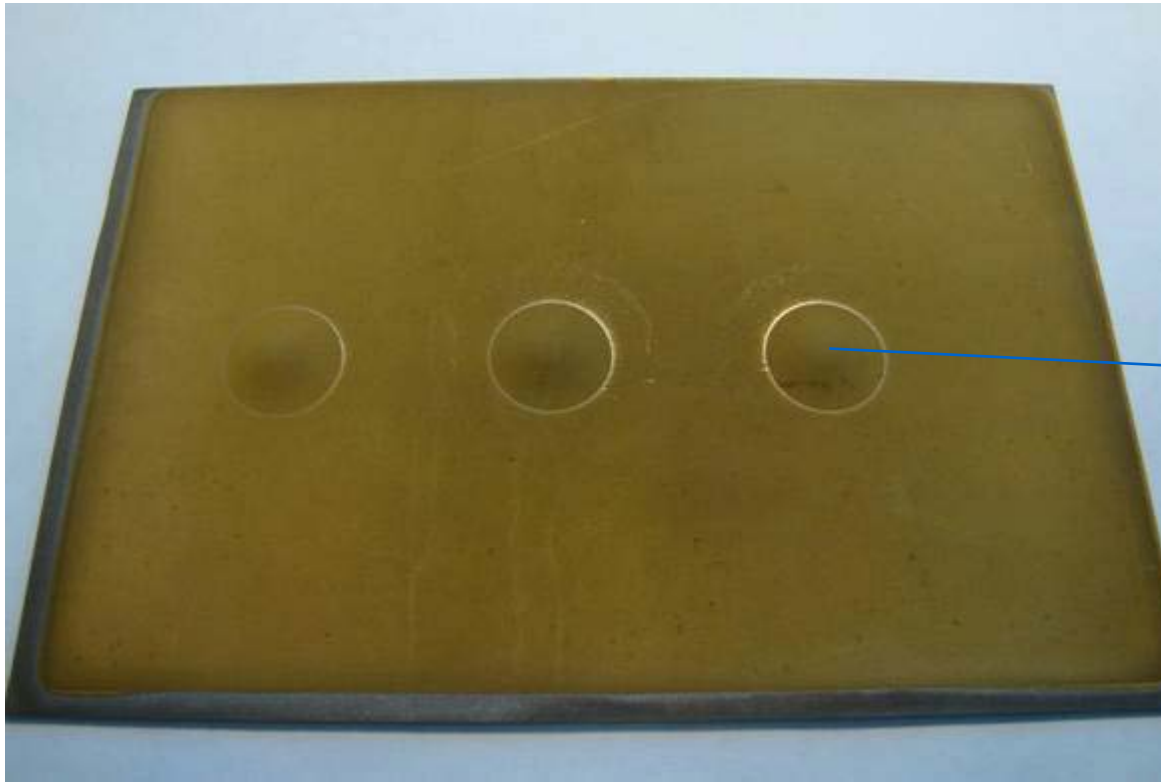
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Additional Adhesion Testing

Cadmium Adhesion Impact Test Result



Impact at 70 in-lbs

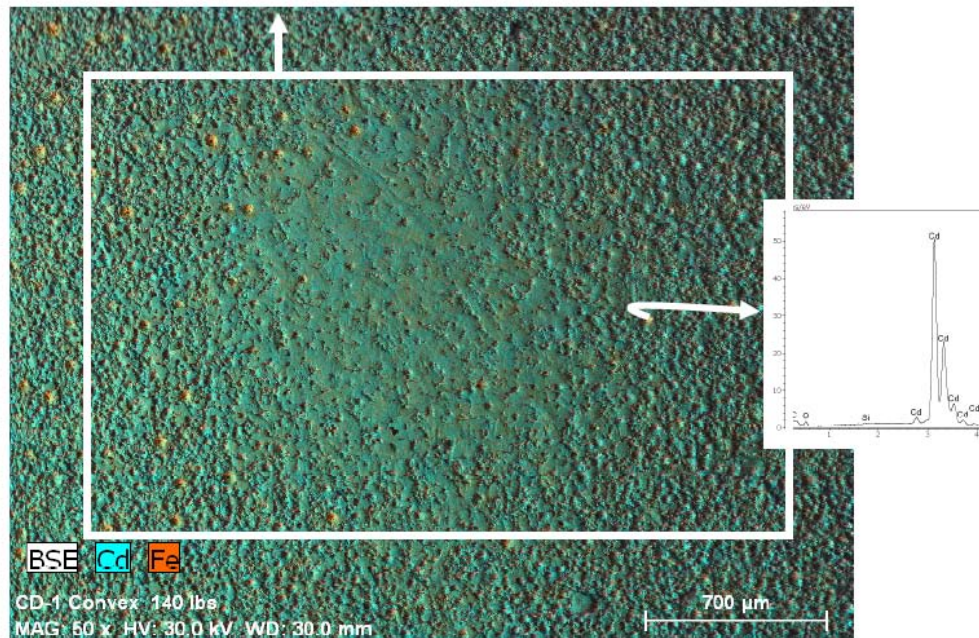
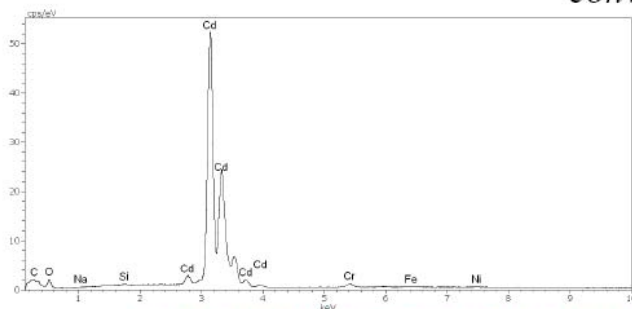


Additional Adhesion Testing

Garner Impact Testing: Cadmium



Specimen CD – 1
convex surface



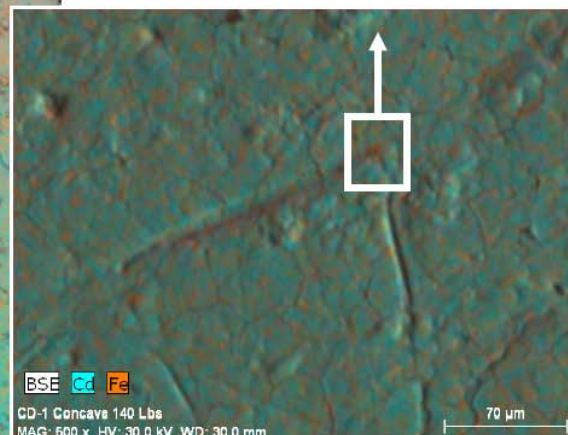
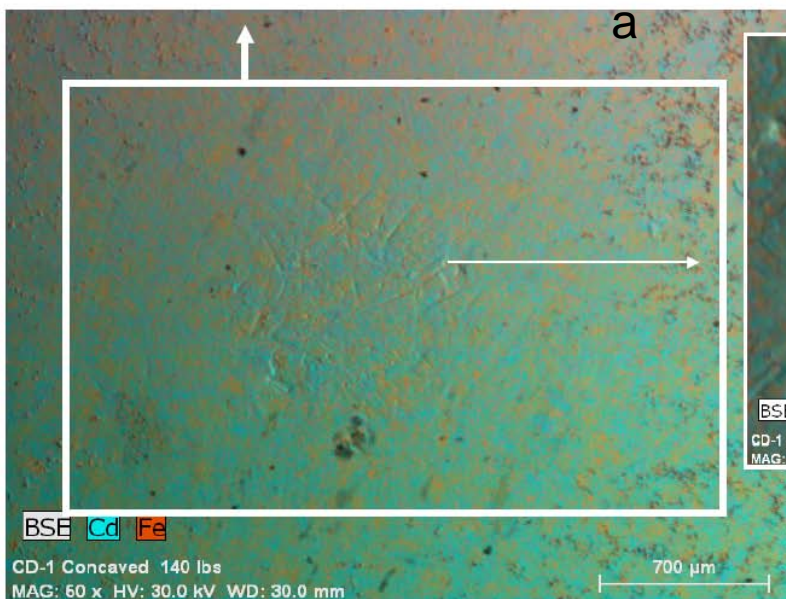
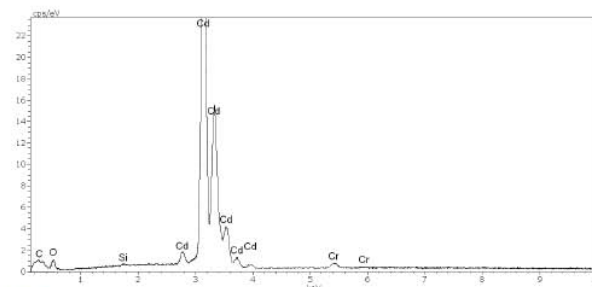
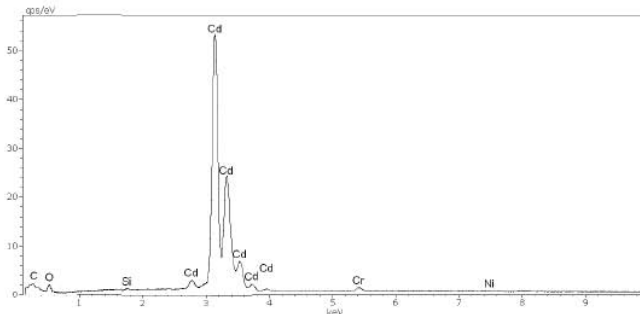


Additional Adhesion Testing

Garner Impact Testing: Cadmium



Specimen CD – 1
concave surface





Additional Adhesion Testing



- **Conclusion: Zn-Ni has good adhesion when tested by bend-to-break and impact test methods**



Additional LHE Zn-Ni Hydrogen Re-Embrittlement Testing



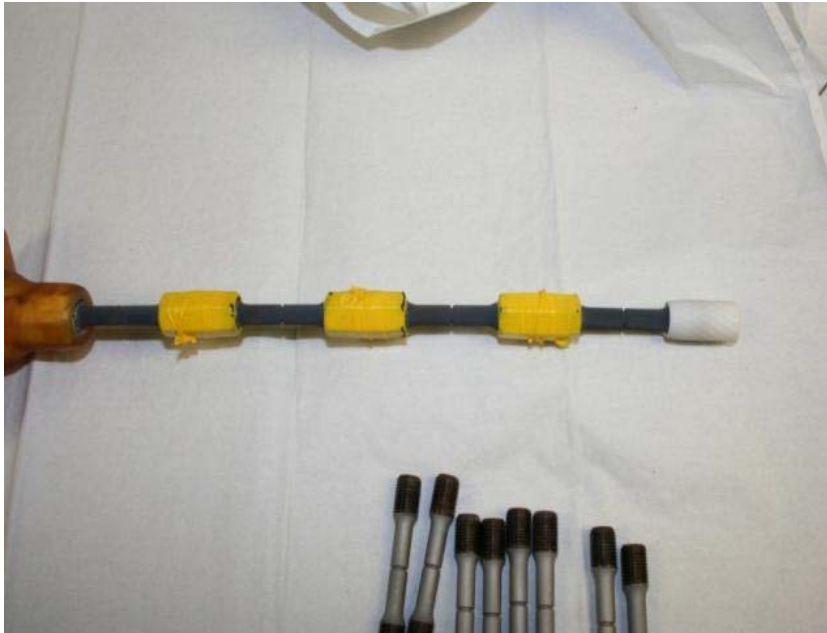
- The original LHE Zn-Ni test coupons failed due to poor plating in notch
- The reason for the poor plating on the original LHE Zn-Ni 1a.1 re-embrittlement coupons are as follows:
 - LHE Zn-Ni tank contamination
 - Spring '09 Lab analysis showed organic contamination
 - The PVC tank liner had begun to break down and had to be replaced in the Summer '09 with a more robust grade of PVC liner
 - Two years operating with new liner with no problems
 - Inconsistent plating in notch area
 - Specimens were chained in series when they were plated for the first series of tests
 - Now a fixture and conformal anode is used to ensure that there is uniform plating throughout the notch area per production process specification
 - Also circulation has been added around the notch area during plating



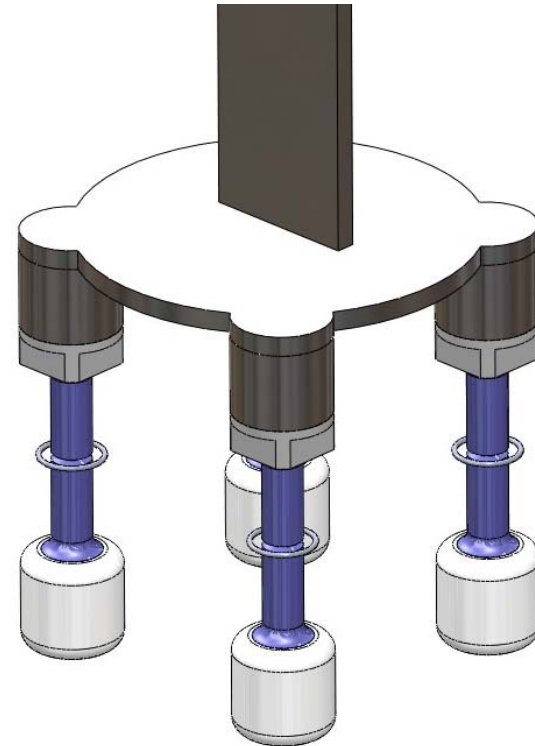
Additional LHE Zn-Ni Hydrogen Re-Embrittlement Testing



Original Coupons Chained in Series

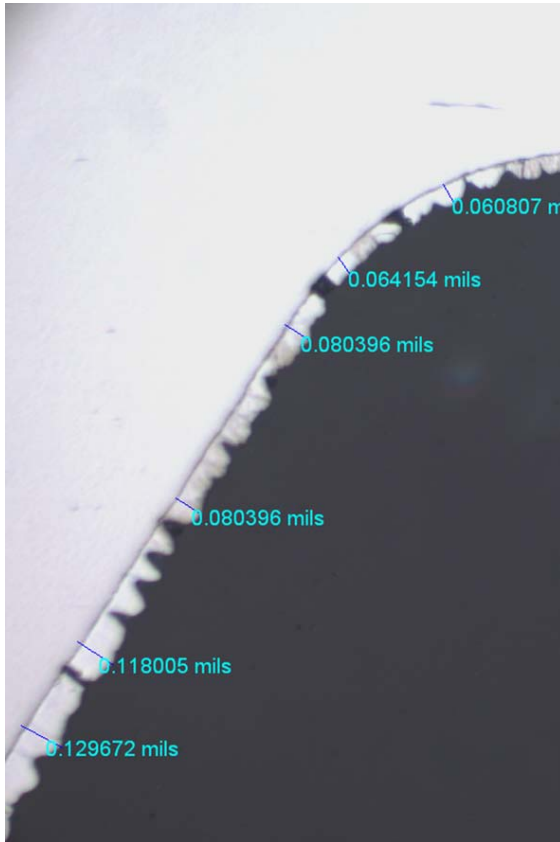


New fixture and Conformal Anode





Additional LHE Zn-Ni Hydrogen Re-Embrittlement Testing



Current plating with fixture
and conformal anode



Contaminated plating
chained in series



Additional LHE Zn-Ni Hydrogen Re-Embrittlement Testing



- Additional, 3.5% salt water, re-embrittlement testing was conducted on LHE Zn-Ni plated coupons and they all passed the ASTM 519-06 150 hour requirement
- Cadmium and IVD Aluminum coupons were not re-tested because they are already approve for use on high strength steel

Re Embrittlement Test Matrix						
Plating	Test Solution					
	Distilled Water @ Room Temp Tested 45% NFS for 150Hrs	3.5% Salt Water @ Room Temp Tested 45% NFS for 150Hrs	Dwg 9825019* Diluted Calla 296 @ Max Temp 180 °F Tested 75% NFS for 200Hrs	Dwg 9825019* Diluted Calla 602 LF Max Temp 160 °F Tested 75% NFS for 200Hrs	Concentrated Calla 296 @ Room Temp tested 45% NFS for 150Hrs	Concentrated Calla 602LF @ Room Temp tested 45% NFS for 150Hrs
LHE Zn-Ni	Passed	Passed	Passed	Passed	Passed	Passed
Cadmium	Passed	Failed	Passed	Passed	Passed	Passed
IVD	Failed	Failed	Not Tested	Not Tested	Not Tested	Not Tested

*The specimens were immersed in the cleaning compound at the manufacturer's maximum recommended temperature, and appropriate cleaning concentration, for 30 minutes. Removed. Air dried and loaded to 75% NFS for 200Hrs.



Additional LHE Zn-Ni Hydrogen Re-Embrittlement Testing



- Due to the inconsistent test results of ASTM 519 re-embrittlement tests, the ASTM 519 committee no longer approves the use of this test for new coatings or platings
- It was originally designed to test new maintenance fluids on cadmium plated components
 - Basically, the maintenance fluids had to have corrosion inhibitors in them so that they would perform better than water during the 45% UTS notch fracture strength testing.
- Army Research Labs, BR&T and 417 SCMS/GUEA are currently developing a new re-embrittlement test for coatings and plating



De-Zincification Testing

- Questions have been raised about the potential impact of dezincification of the Zn-Ni plating
- 417 SCMS/GUEA, BR&T and ES3 are currently reviewing past industry de-zincification studies
 - Initial findings show that the corrosion electro-potential is consistent throughout the corrosion process
- 417 SCMS/GUEA, BR&T and ES3 will identify any additional testing that might be required to address dezincification



Specification Drawing



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Source Control Drawing



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REV STATUS OF SHEETS		REV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		SHEET															
		REV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		SHEET															
		REV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		SHEET															
		REV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<p align="center">SOURCE CONTROL DRAWING</p>																	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		DESIGN		DATE		U.S. AIR FORCE											
TOLERANCE ON FRACTIONS DECIMALS ANGLES		STEVE RANSON		12/04/16		TITLE											
± .001 ± .0004 ±		CHGR		12/05/01		Solutions For Use In LHE Zinc - Nickel Plating On High Strength Steel Substrate (>180 KSI) Landing Gear Components											
		ROONEY GOULD		12/05/01		SIZE											
		N/A				CAGE CODE											
		PROJ ENGR		12/04/00		DWG NO.											
		DAVE FREDERICK		12/04/00		REV											
		A.P. AUTHENTICATION		12/04/00		A 98747 201027457											
CURRENT CAGE CODE		RON MONTGOMERY		12/04/00		SCALE											
		RELEASE		12/05/04		NONE											
		RICK HARRISON		12/05/04		SHEET 1 OF 15											
EF (MS WORD)																	



Phase III Effort Prototype Process Line

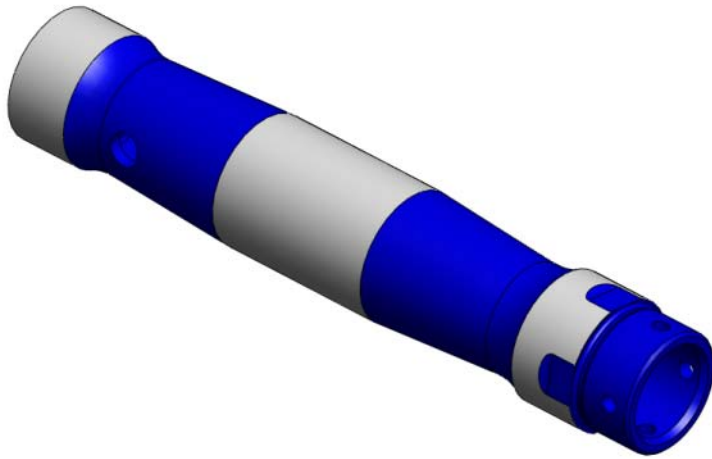


Prototype Part Matrix

Component	Part #
C-5 MLG Stop Plate	4G11453-101B
F-15 MLG Outer Cylinder	68A412702-1001/1002
B-1 MLG Axle	1881B85
F-15 MLG Lower Drag Brace	68A410792-2001
A-10 MLG Torque Arm	19046-1
F-16 NLG Inner Cylinder	2007644-103
C-5 MLG Rotation Collar	4G13565-101A/-101B
A-10 NLG Axle	18800-3



Phase III Effort Solid Model Prototype Parts



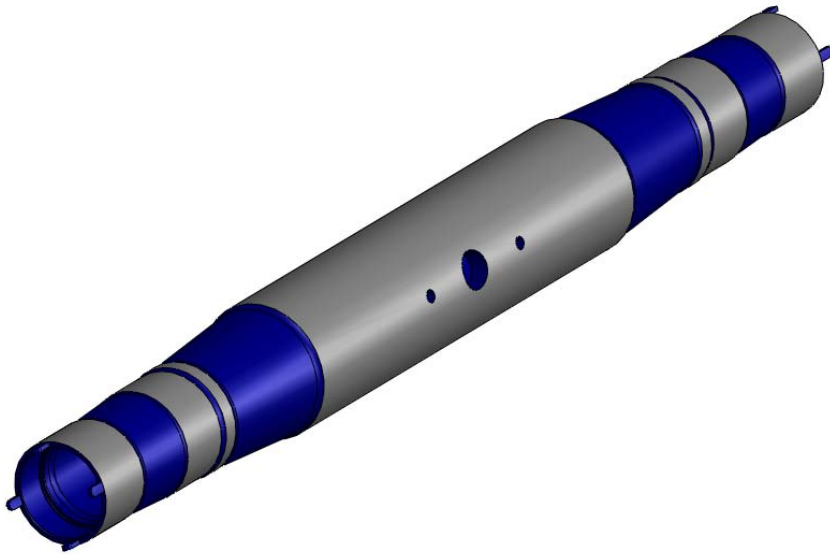
A-10 NLG Axle



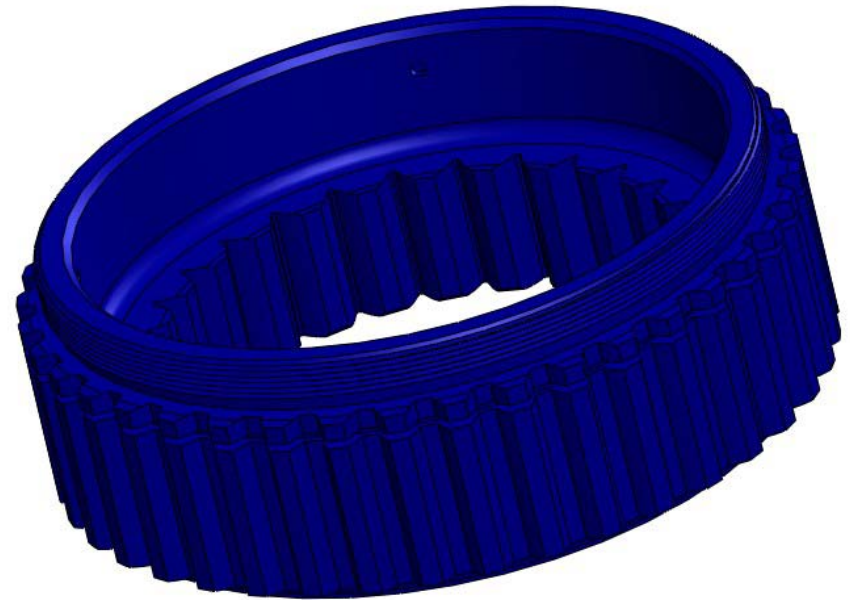
A-10 MLG Torque Arm



Phase III Effort Solid Model Prototype Parts



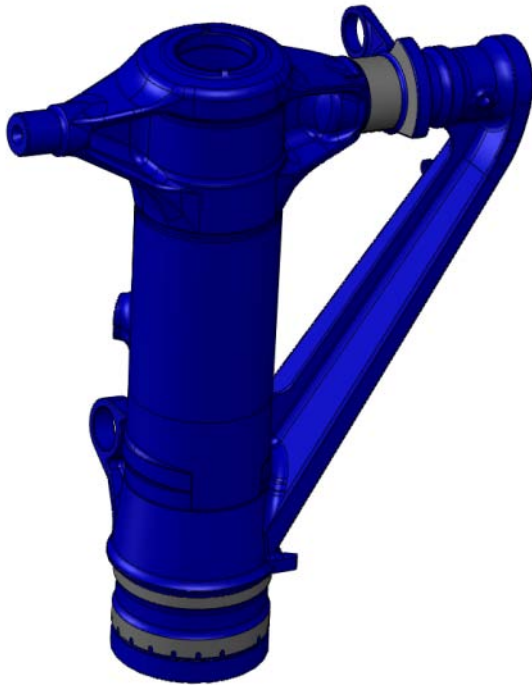
B-1 MLG Axle



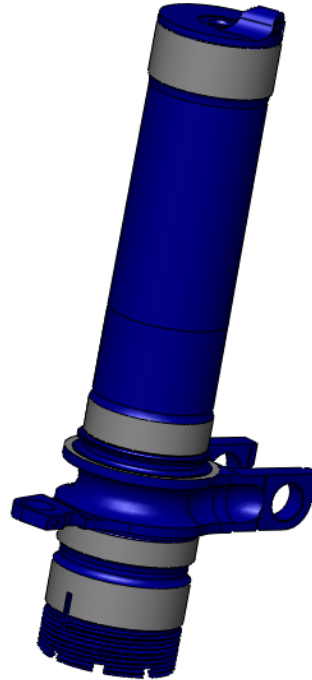
C-5 MLG Rotation Collar



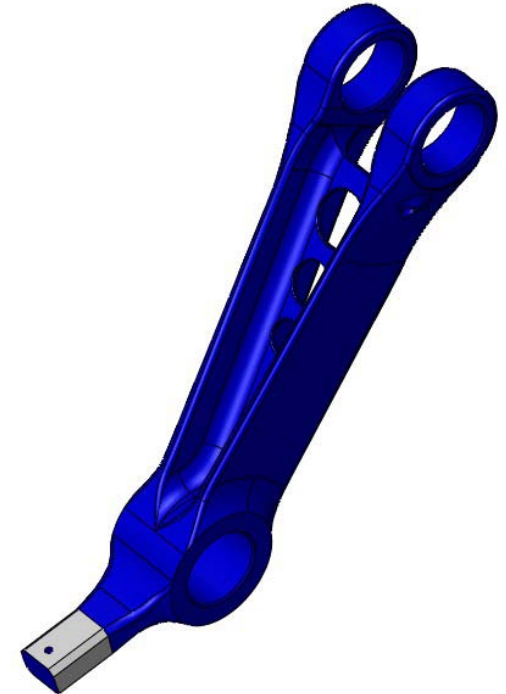
Phase III Effort Solid Model Prototype Parts



F-15 MLG Cylinder



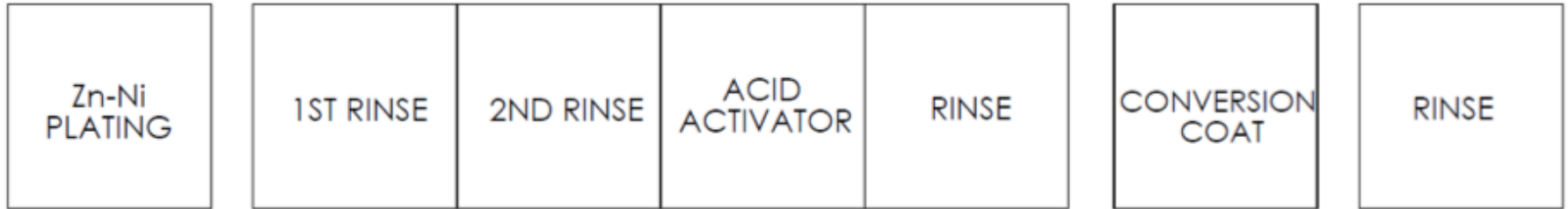
F-16 NLG Inner Cylinder



F-15 MLG Lower Drag Brace



LHE Zn-Ni Plating Process



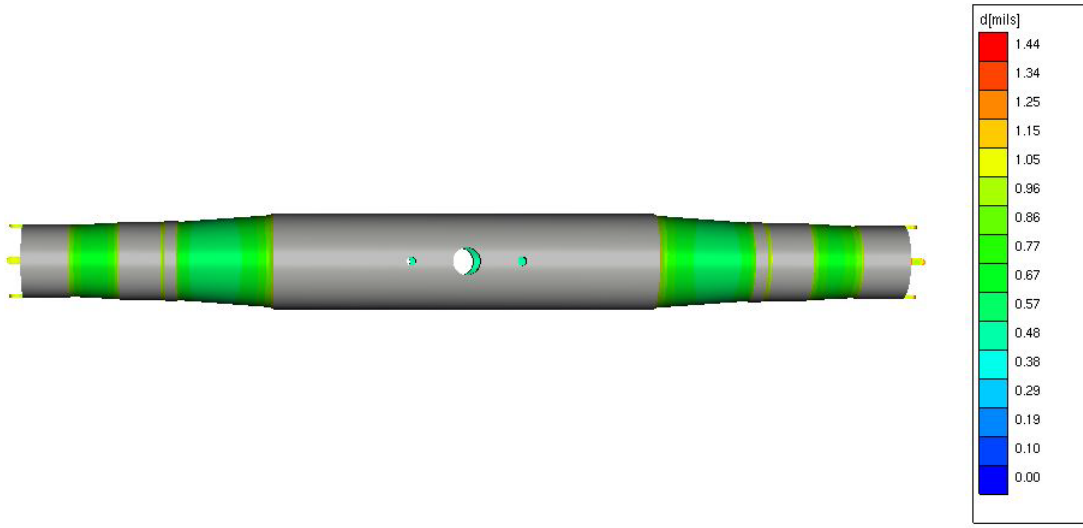
Prototype LHE Zn-Ni Plating
Tank



Prototype Tri-Chromium
Conversion Coating Tank



Prototype Conformal Anode & Fixture Design



Conformal
Anode &
Fixture

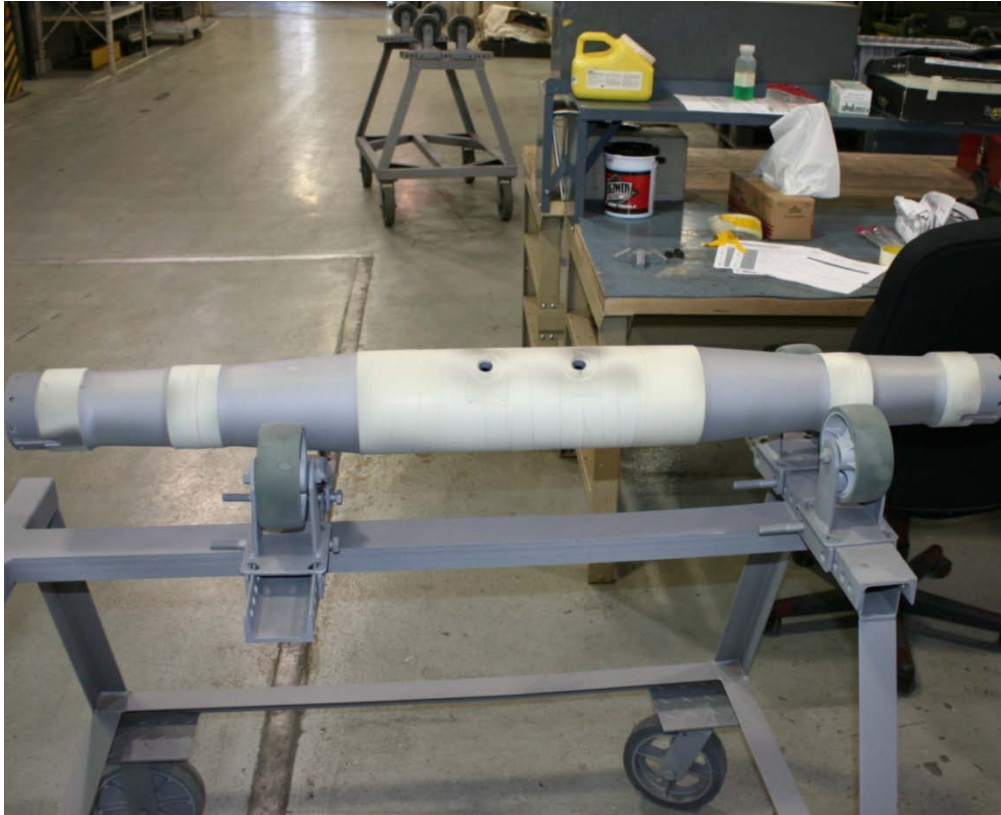


Conformal
Anode &
Fixture

LHE Zn-Ni Plated MLG Axle



MLG Axle Plating



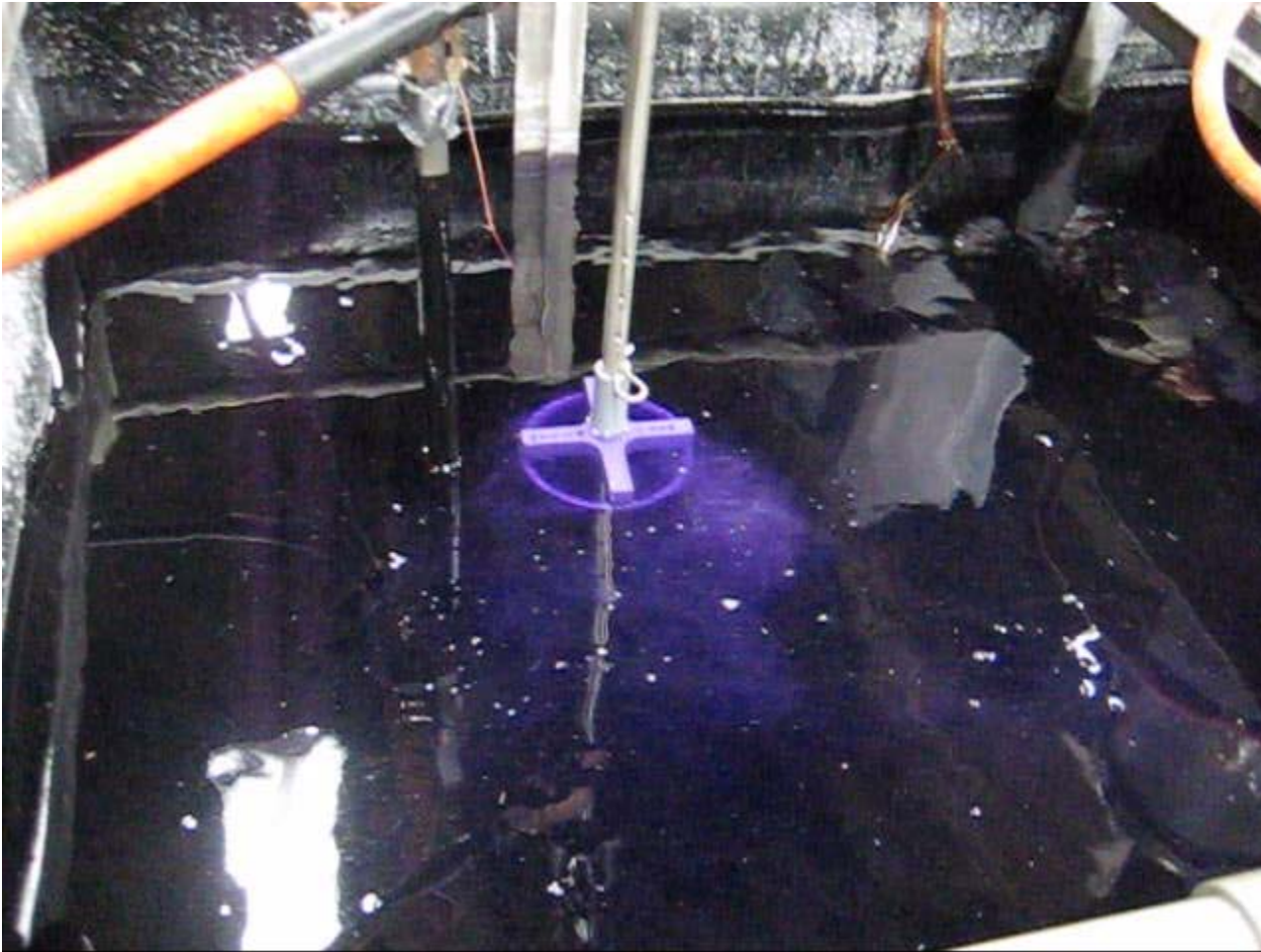
MLG Axle before Fixture



MLG Axle with Fixture



MLG Axle During LHE Zn-Ni Plating



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MLG Axle after LHE Zn-Ni Plating



MLG Axle Finished Plated Outer Diameter



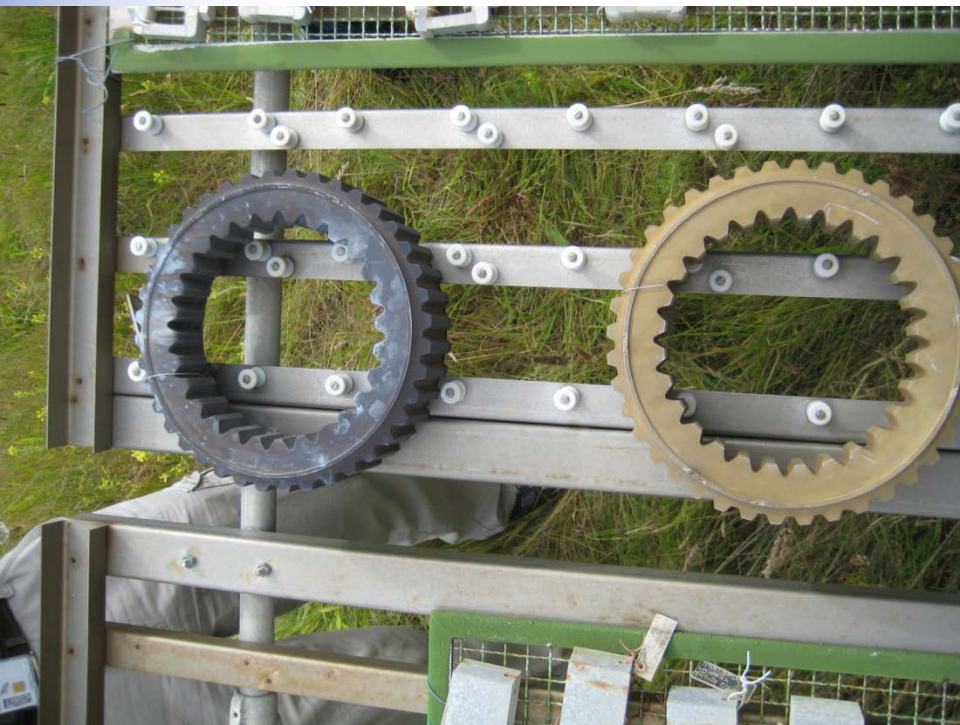
MLG Axle Finished Plated Inner Diameter



LHE Zn-Ni Plating – Ph III (FY 12) Component Corrosion Eval. (Whidbey Island)



F-15 MLG Lower Drag
Brace



C-5 MLG Rotation Collar

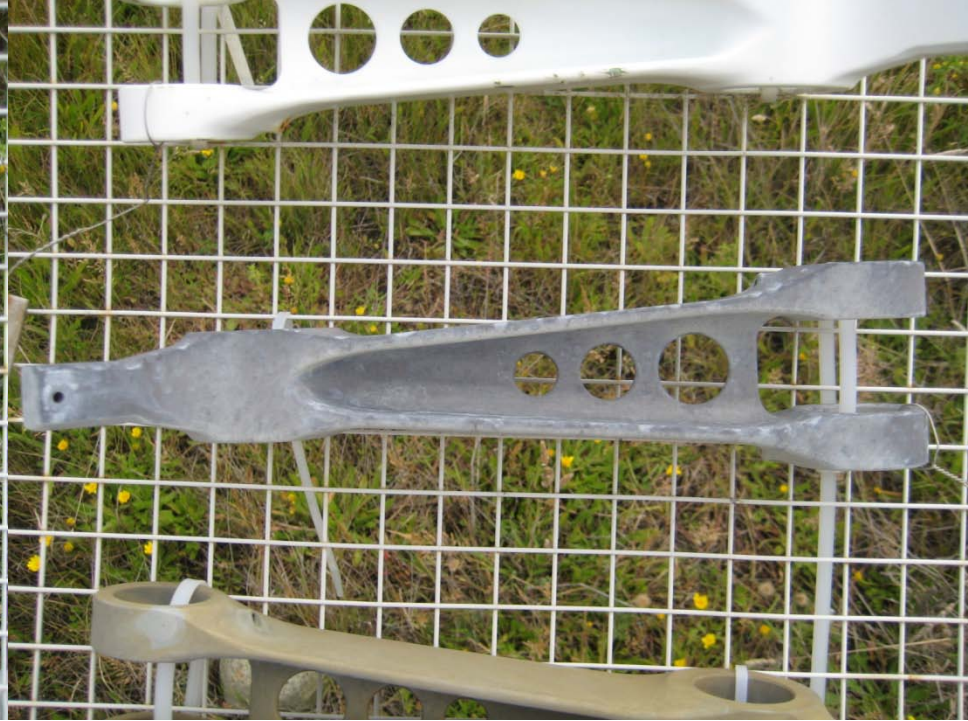
Parts Placed 10/13/2010, Pictures taken 7/24/2012



LHE Zn-Ni Plating – Ph III (FY 12) Component Corrosion Eval. (Whidbey Island)



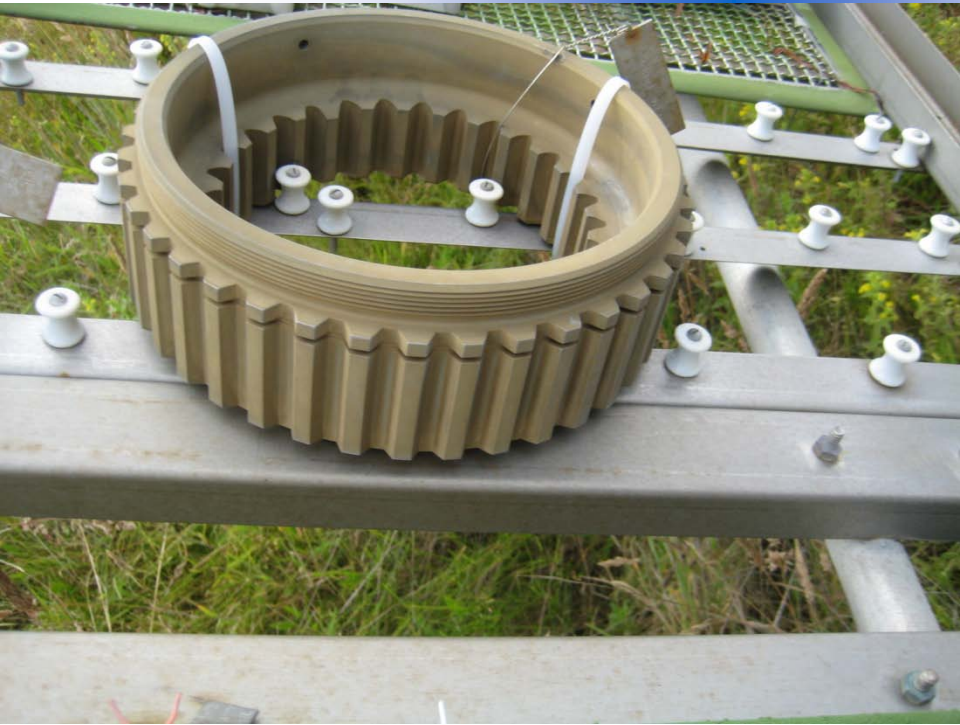
F-15 MLG Lower Drag
Brace CAD



F-15 MLG Lower Drag
Brace Zn-Ni



LHE Zn-Ni Plating – Ph III (FY 12) Component Corrosion Eval. (Whidbey Island)



C-5 MLG Rotation Collar
CAD



C-5 MLG Rotation Collar
Zn-Ni



LHE Zn-Ni Plating – Ph III (FY 12) Component Corrosion Eval. (Cape Kennedy)



F-15 MLG Lower Drag
Brace



C-5 MLG Rotation Collar

Parts Placed 9/30/2010, Pictures taken 8/07/2012



LHE Zn-Ni Plating – Ph III (FY 12) Component Corrosion Eval. (Cape Kennedy)



F-15 MLG Lower Drag
Brace CAD

F-15 MLG Lower Drag
Brace Zn-Ni

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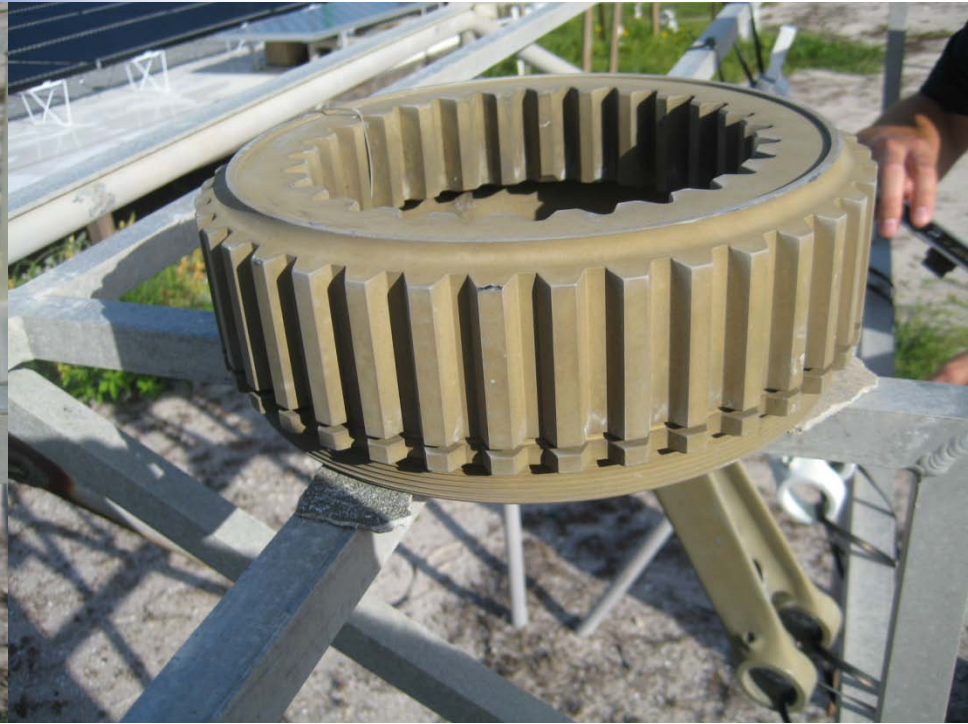
STRENGTH AND HONOR



LHE Zn-Ni Plating – Ph III (FY 12) Component Corrosion Eval. (Cape Kennedy)



C-5 MLG Rotation Collar
CAD



C-5 MLG Rotation Collar
Zn-Ni



LHE Zn-Ni Performance Tracking Program (PTP)



- **Criteria for part selection**
 - **Fixture Completed**
 - **2 to 3 Parts from each Weapon System (NLG & MLG)**
 - **Ease of access to component on aircraft**
 - **Air Force Base**
 - **Location**
 - **Corrosive Environment**
 - **Overhauled at Hill AFB**



LHE Zn-Ni Performance Tracking Program (PTP) Components



Weapon System	Component	<u>BASE 1</u>	<u>BASE 2</u>	BASE 3
C-130	MLG TORQUE STRUT AFT P/N 388066-3	Kadena AB AFSOC	Hurlburt, FL ACTIVE	
C-130	MLG TORQUE STRUT FWD P/N 388065-3			
F-15	MLG LOWER DRAG BRACE 68A410792-2001	Kadena AB PACAF	Jacksonville, FL ANG	
F-15	MLG PISTON P/N 68A410704-1011 (LH) P/N 68A410704-1012 (RH)			
F-16	MLG TENSION STRUT P/N 2007003-3	Shaw AFB, NC	Kunsan AB, PACAF	
F-16	MLG COLLAR P/N 2007307-105 (LH) P/N 2007307-106 (RH)			
F-16	MLG DRAG BRACE P/N 2007304-101			
KC-135	MLG BRAKE EQUALIZER ROD P/N 65-1266-2	Kadena AB PACAF	Hickam AFB, HI ANG	MacDill AFB, FL AMW
KC-135	MLG BRAKE COLLAR P/N 8853035-05			

NOTE: Bases with multiple aircraft systems are highlighted in color



C-130 Main Landing Gear PTP Components



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STRENGTH AND HONOR



F-15 Landing Gear PTP Components



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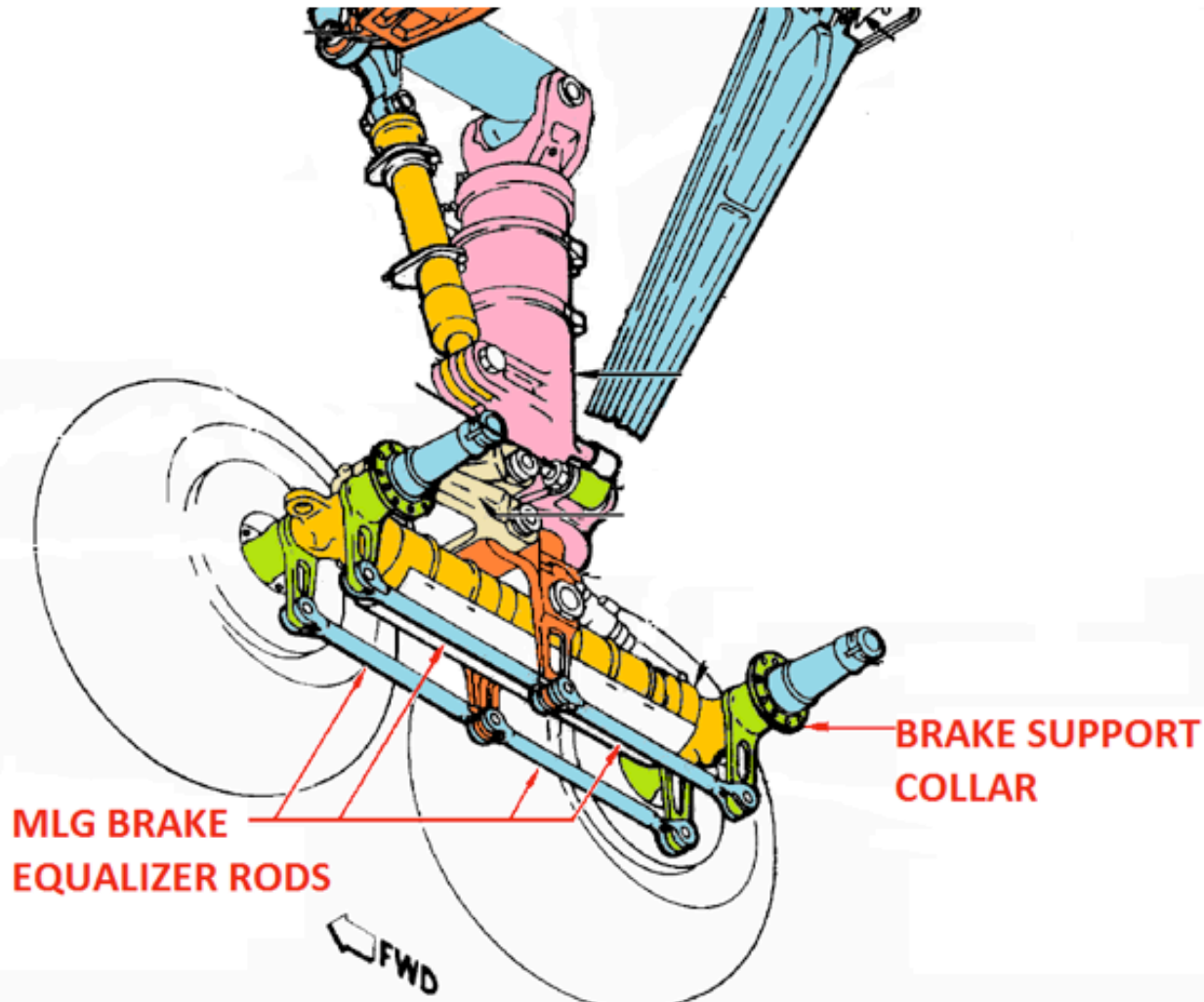


F-16 Landing Gear PTP Components



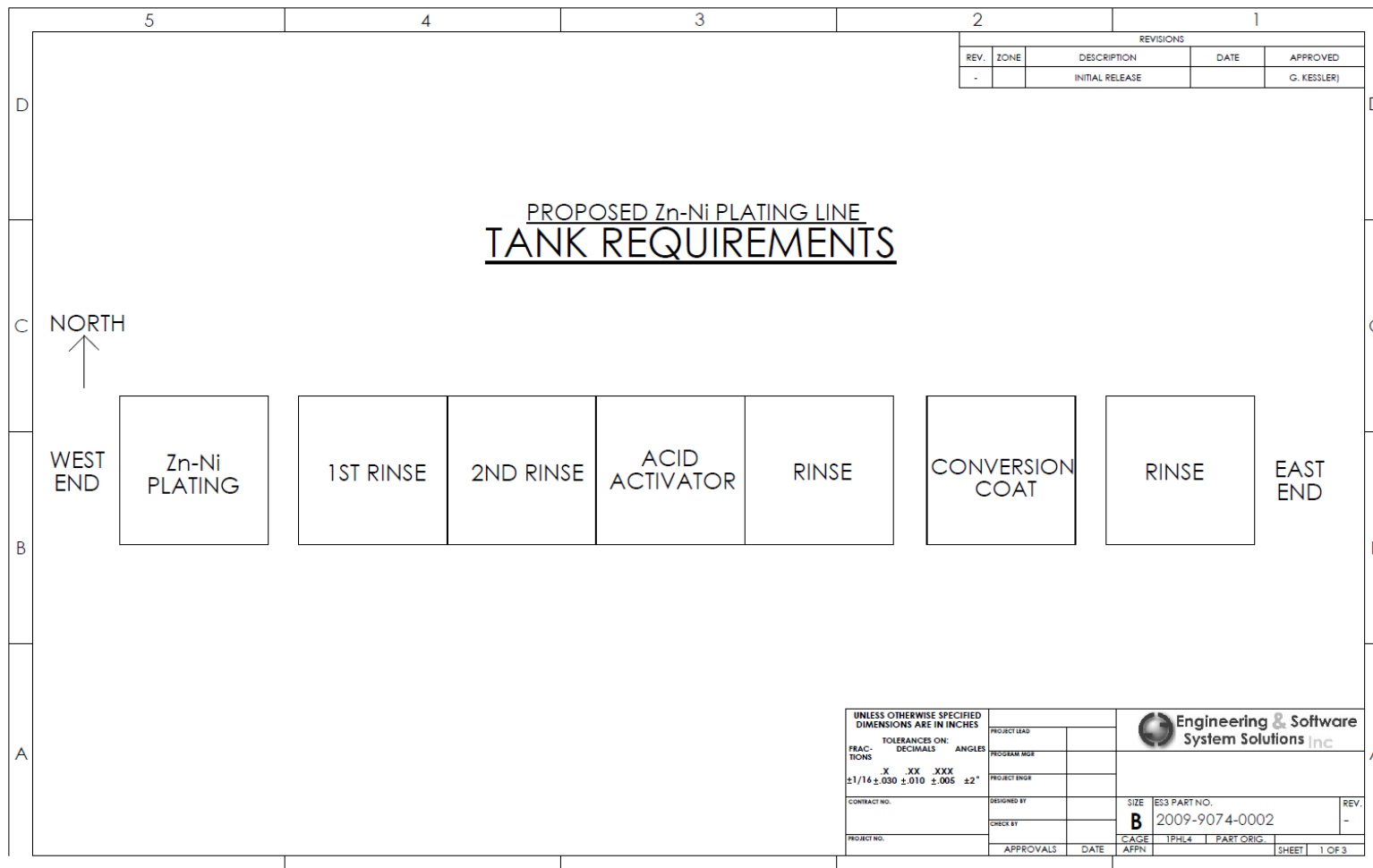
BE AMERICA'S BEST

STRENGTH AND HONOR



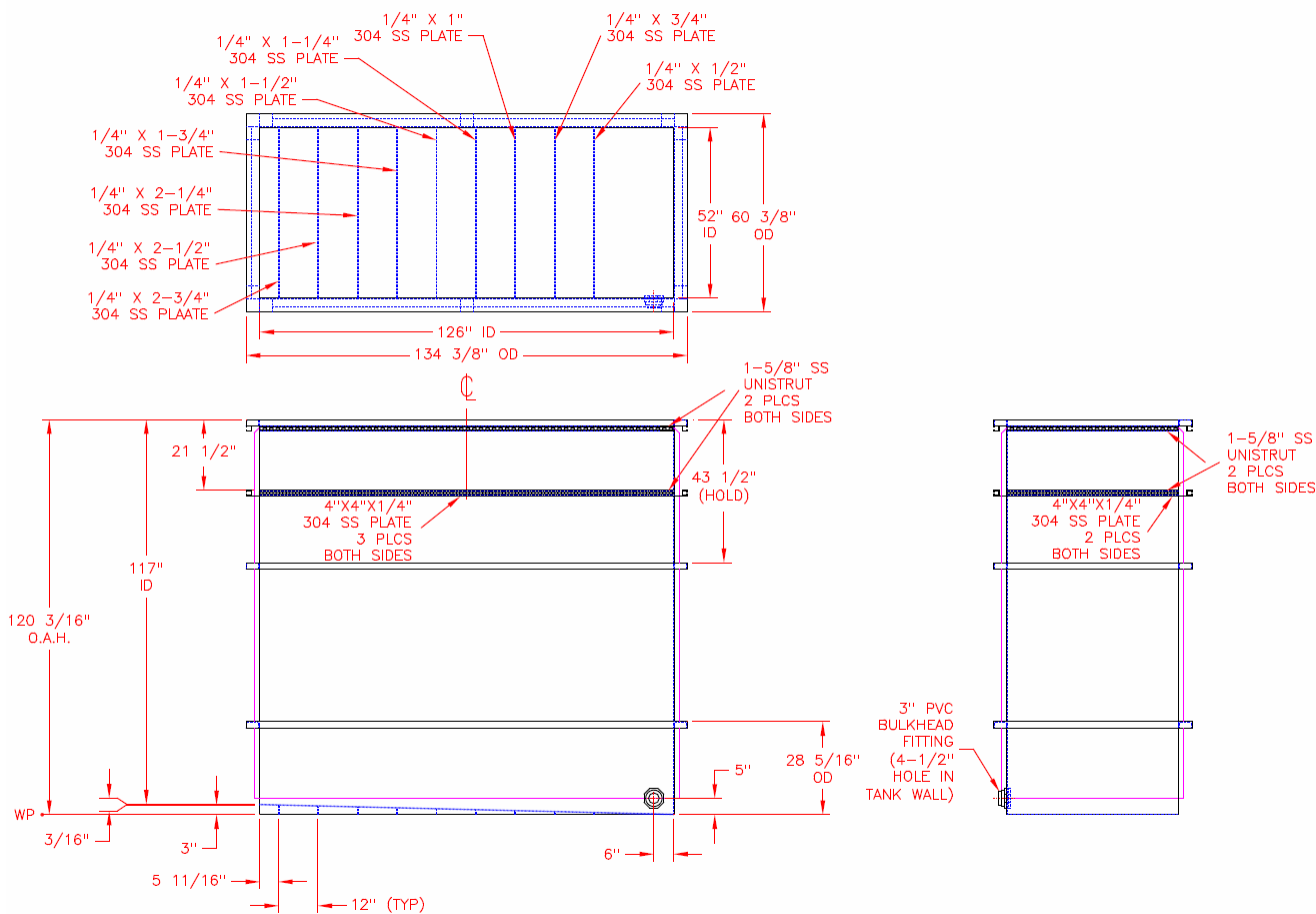


ESTCP/P2/STTP Effort Full Size Prototype Plating Line



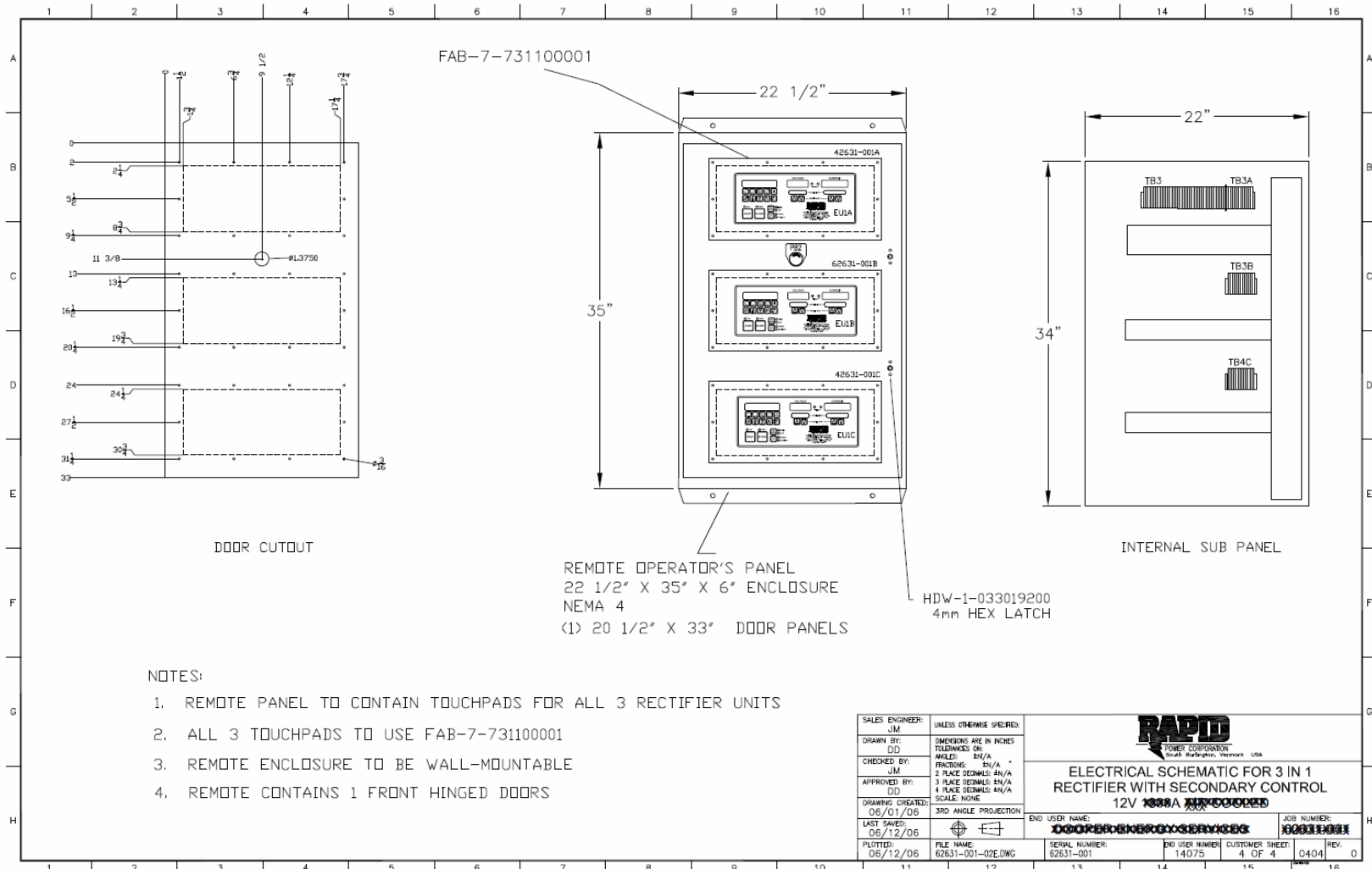


LHE Zn-Ni Prototype Plating Line Tank Drawing



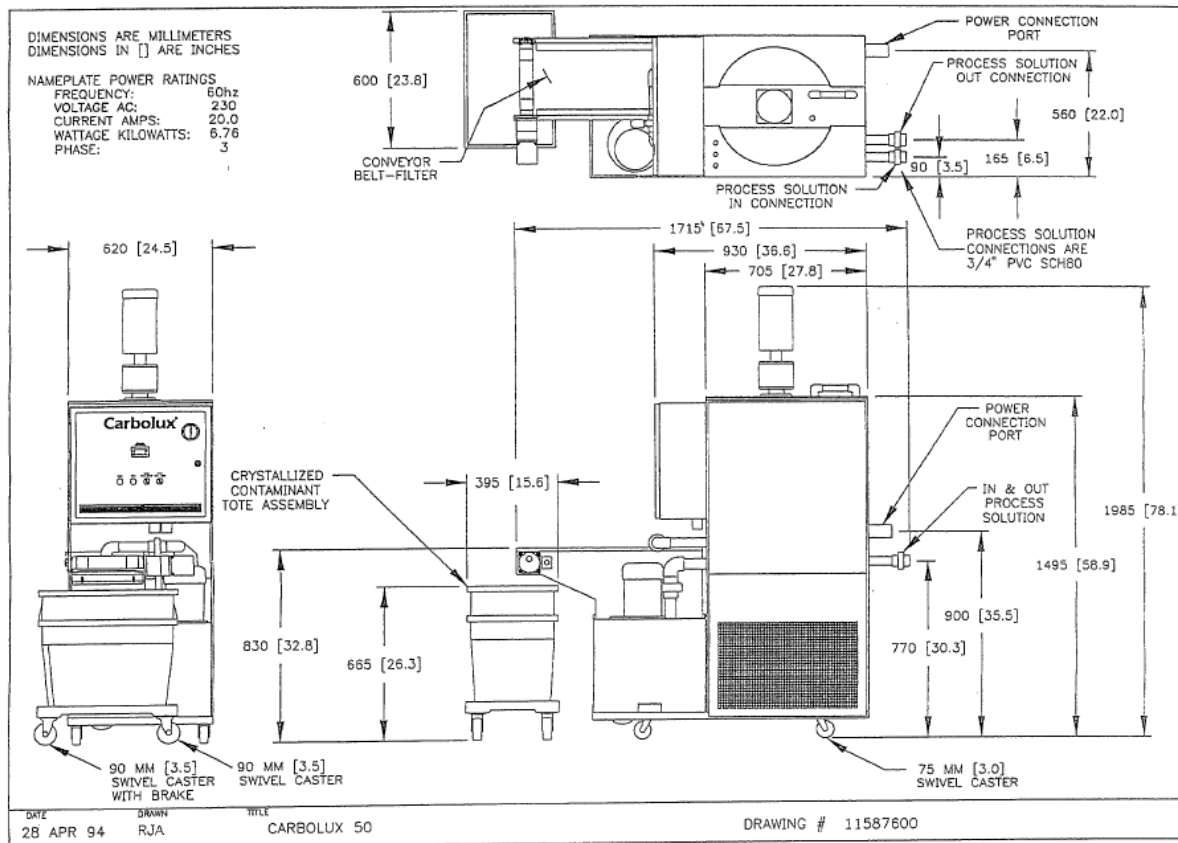


LHE Zn-Ni Prototype Plating Line Rectifier Controller





LHE Zn-Ni Prototype Plating Line Carbolux™ System





Removal of Oven 3 for LHE Zn-Ni Prototype Plating



Before, view from
plating line



After, view from basement



LHE Zn-Ni Prototype Line Installation/Demolition



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Questions



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Back Up Slides: Phase II Qualification Testing



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Small Prototype Tank Implementation



- ES3 has implemented a tank of approximately 325 gallons for the purpose of demonstrating the LHE Zn-Ni plating process on some full sized gear components
- The demonstration tank was used to develop uniform plating thicknesses and process parameters on test coupons and full scale landing gear components
- During the plating operations Quality Assurance testing has been conducted to ensure the alkaline LHE Zn-Ni solution is within proper process limits



LHE Zn-Ni Plating Tank



Prototype Tank Implementation



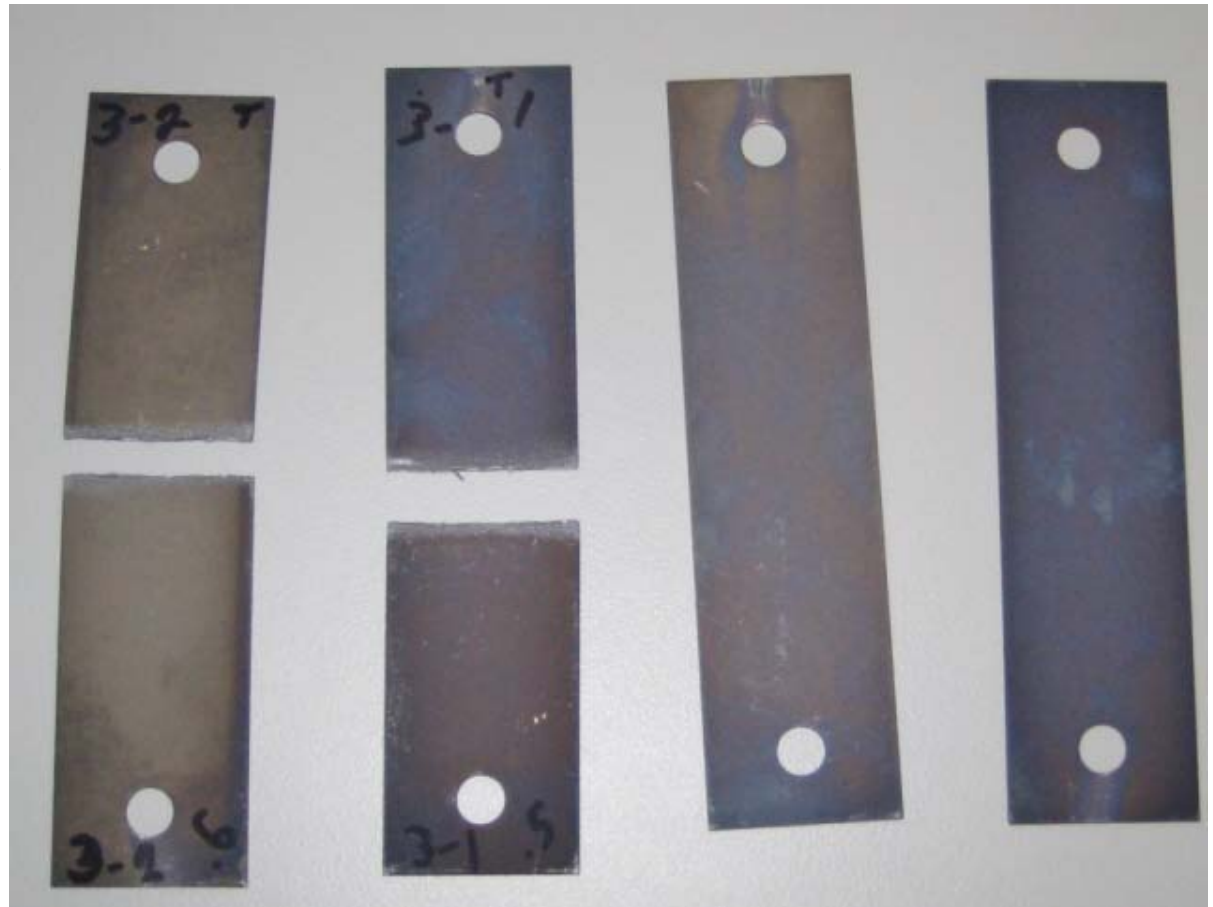
Tri-Chromium Conversion Coat Tank



Bend to Break Adhesion Test Coupons



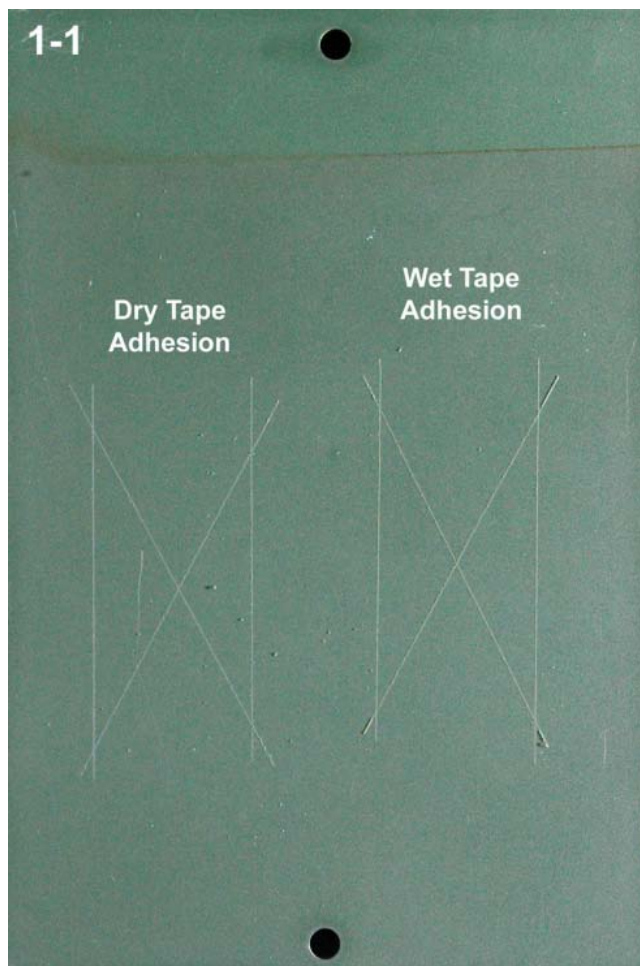
- Adhesion of the LHE Zn-Ni coating to the substrate was tested per ASTM B571
- All adhesion test coupons were manufactured from 1"x 4"x 0.040" 4130 steel sheet
- Results: All Test coupons passed



Adhesion Test Coupons



LHE Zn-Ni Test Panels After Dry and Wet Tape Adhesion Test of Primer (Passed)



Deft 44-GN-072



Deft 44-GN-098



Dry and Wet Paint Adhesion Test Results per ASTM D3359 (Passed)



Scribed Dry and Wet Tape Adhesion Test Results

4" x 6" x 0.040" 4130 Steel Substrate

				DRY TAPE ADHESION			WET TAPE ADHESION		
PANEL	ID	PRETREATMENT	COATING	PERCENTAGE COATING REMOVED	ASTM D 3359 (1)	Pass / Fail (2)	PERCENTAGE COATING REMOVED	ASTM D 3359 (1)	Pass / Fail (2)
1		LHE Zn-Ni Plating	Deft 44-GN-72	0	5A	Pass	0	4A	Pass
2				0	5A	Pass	2	4A	Fail
3				0	5A	Pass	0	5A	Pass
1		Cd Plated w/ Hex Cr Conversion Coating		0	5A	Pass	0	5A	Pass
2				0	5A	Pass	0	5A	Pass
3				0	5A	Pass	0	5A	Pass
4		LHE Zn-Ni Plating	Deft 44-GN-098	0	5A	Pass	0	5A	Pass
5				0	5A	Pass	0	5A	Pass
6				0	5A	Pass	10	4A	Fail
4		Cd Plated w/ Hex Cr Conversion Coating		0	5A	Pass	0	5A	Pass
5				0	5A	Pass	0	5A	Pass
6				0	5A	Pass	0	5A	Pass

Notes:

Panels immersed in distilled water at room temperature for 24 hours.

[1]- ASTM D 3359 Criteria:

5A - No peeling or removal

4A - Trace peeling or removal along incisions

3A - Jagged removal along incisions up to 1/16 inch on either side

2A - Jagged removal along most of incisions up to 1/8 inch on either side

1A - Removal from most of the area of the "X" under the tape

0A - Removal beyond the area of the "X"

[2]- The primer shall show no adhesion failure.



LHE Zn-Ni Hydrogen Embrittlement Testing



- Coupons manufactured per ASTM F519 specifications (4340)
- Coupons plated and tested 28th April, 2009 upon initial installment of LHE Zn-Ni demonstration tank
- Additional coupons plated and tested at additional dates
- All coupons tested per ASTM F519 and passed the 200 hour sustained load tests @ 75% of the tensile notch fracture strength

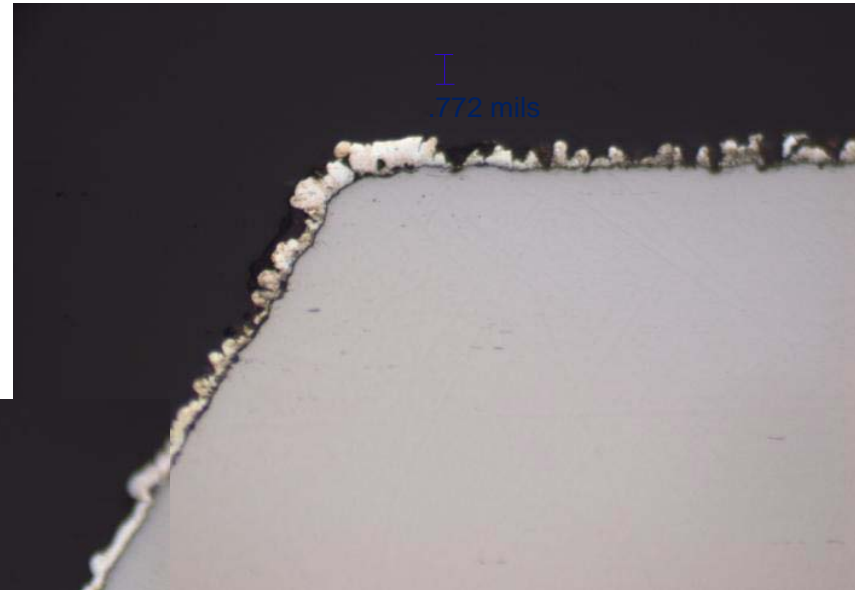
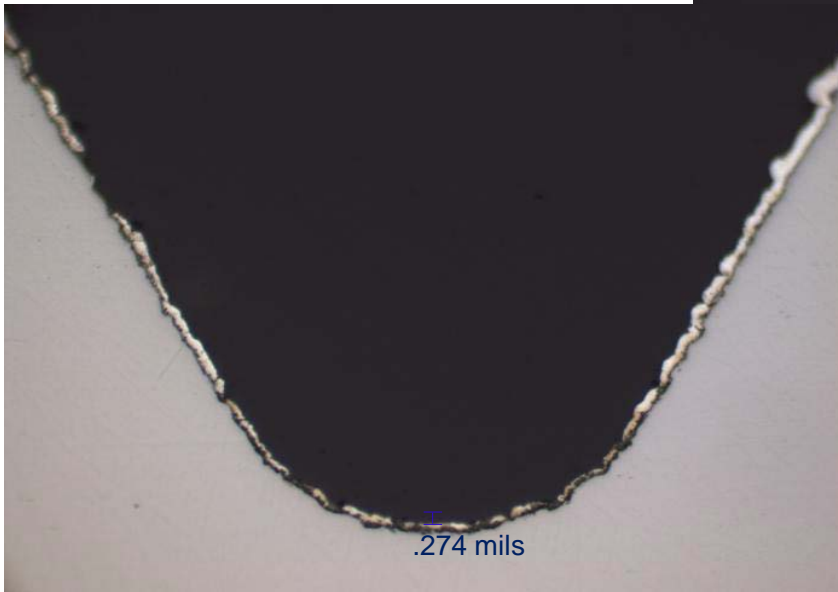


ASTM F519 Type 1A.1 Test Coupons



HE Plated Cross Section

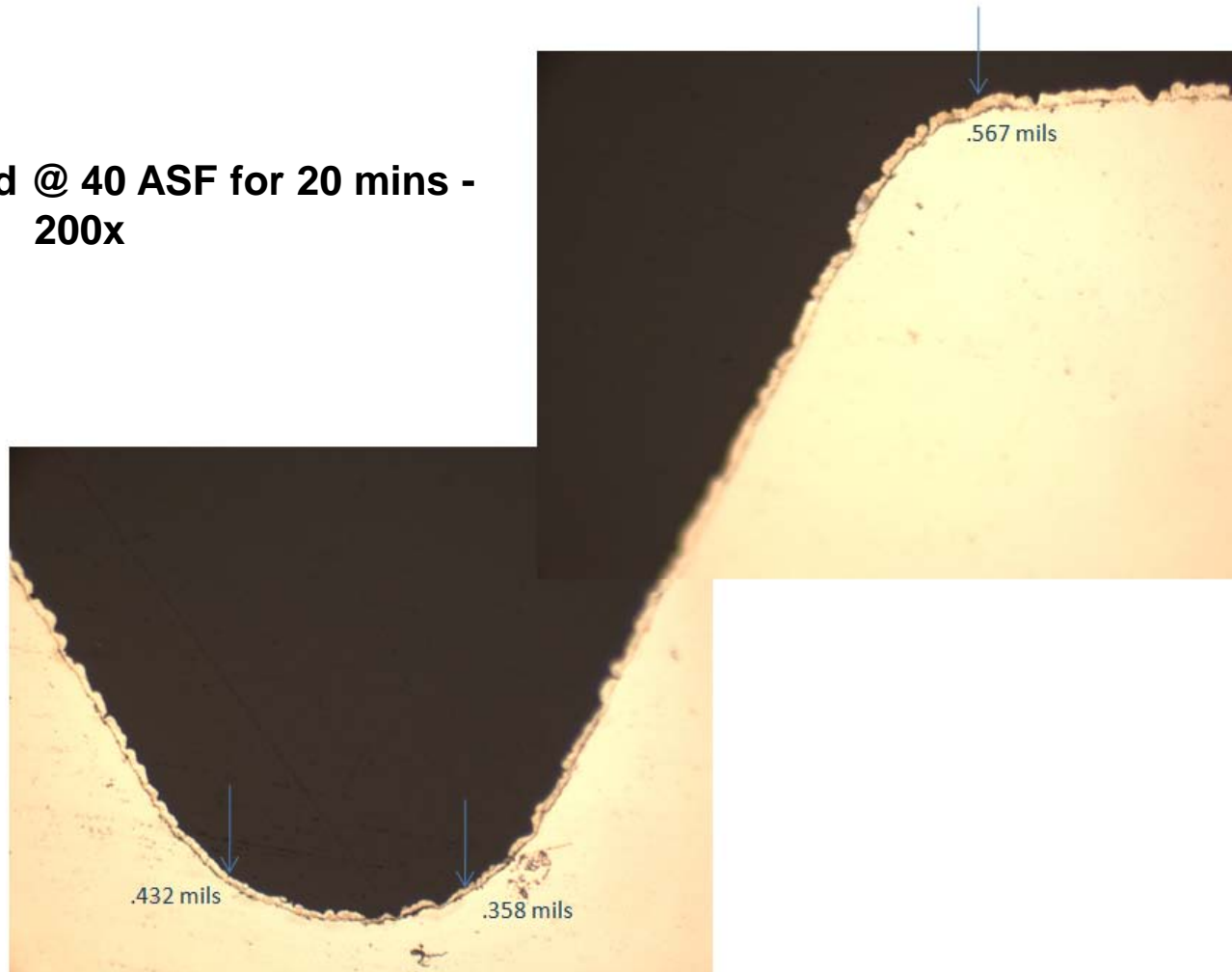
Cad Plated in Bldg 505 for 5 mins - 200x





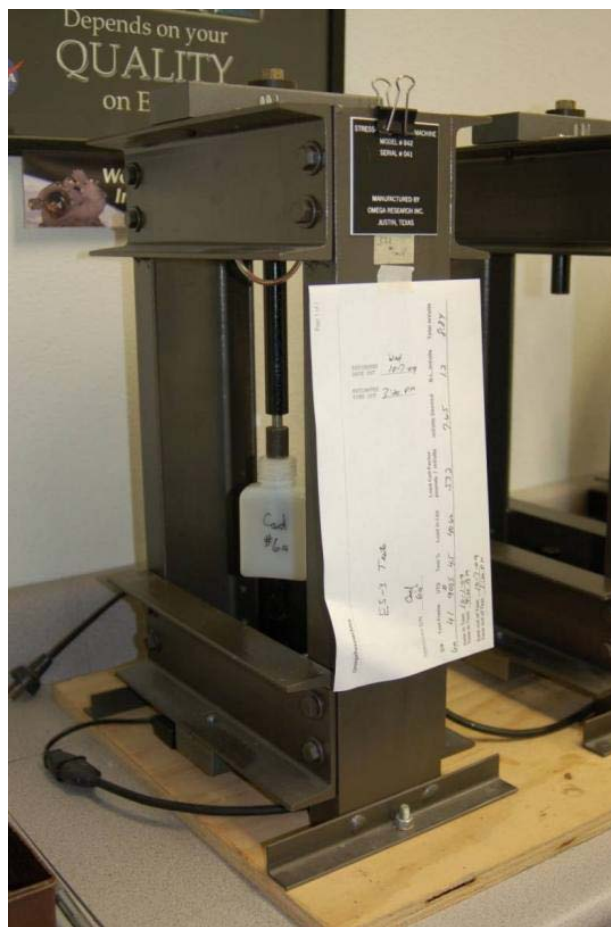
HE Plated Cross Section

**LHE Zn-Ni Plated @ 40 ASF for 20 mins -
200x**





LHE Zn-Ni Hydrogen Re-Embrittlement Testing



LHE Zn-Ni Re-Embrittlement Testing Machine



Original LHE Zn-Ni Hydrogen Re-Embrittlement Testing



Re Embrittlement Test Matrix						
Plating	Test Solution					
	Distilled Water @ Room Temp Tested 45% NFS for 150Hrs	3.5% Salt Water @ Room Temp Tested 45% NFS for 150Hrs	Dwg 9825019* Diluted Calla 296 @ Max Temp 180 °F Tested 75% NFS for 200Hrs	Dwg 9825019* Diluted Calla 602 LF Max Temp 160 °F Tested 75% NFS for 200Hrs	Concentrated Calla 296 @ Room Temp tested 45% NFS for 150Hrs	Concentrated Calla 602LF @ Room Temp tested 45% NFS for 150Hrs
LHE Zn-Ni	Pass	Failed	Pass	Pass	Pass	Pass
Cadmium	Pass	Failed	Pass	Pass	Pass	Pass
IVD	Failed	Failed	Not Tested	Not Tested	Not Tested	Not Tested

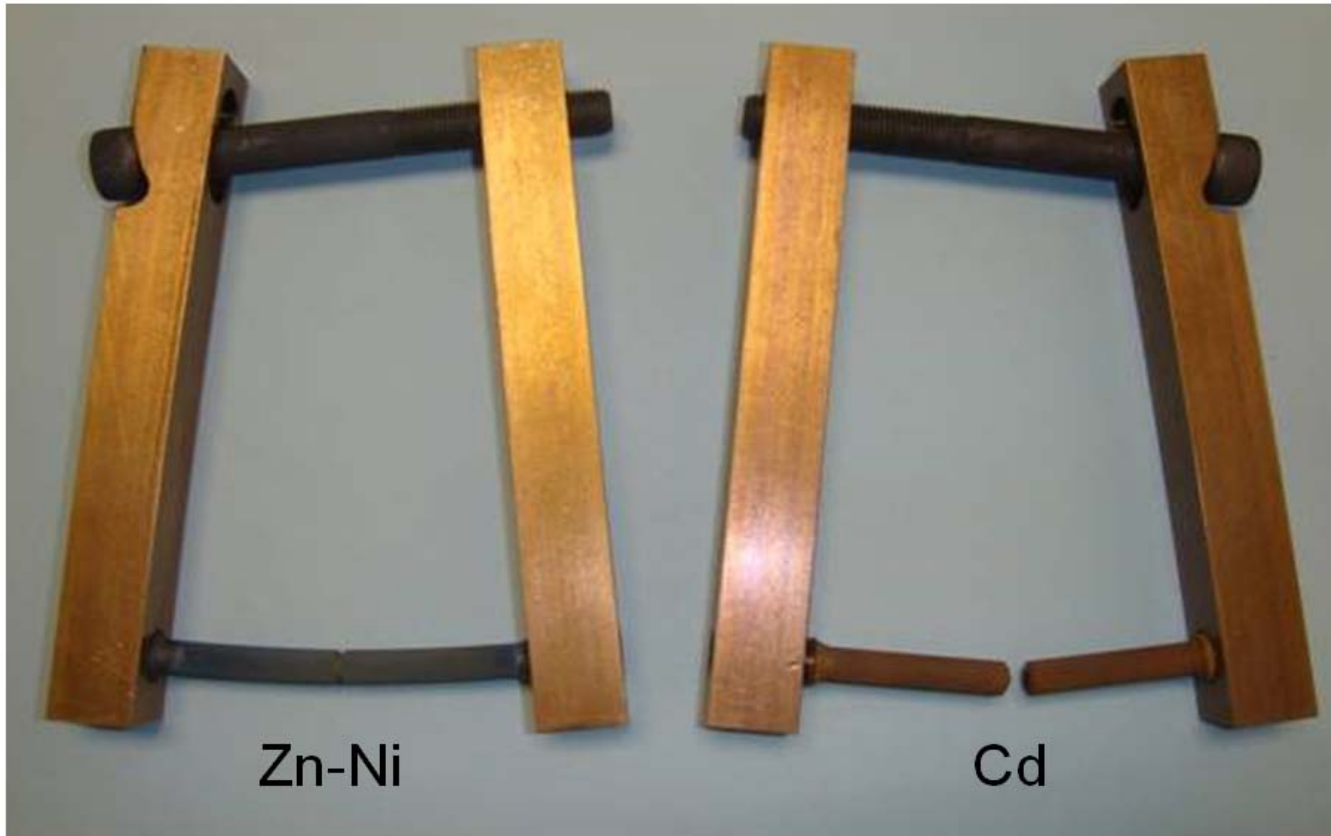
*The specimens were immersed in the cleaning compound at the manufacturer's maximum recommended temperature, and appropriate cleaning concentration, for 30 minutes. Removed. Air dried and loaded to 75% NFS for 200Hrs.

Re-Embrittlement results:

- Coupons tested by an ISO 9001 certified facility. Coupons tested IAW ASTM F519.
The coupons tested immersed in solutions of Water, 3.5% Salt Water, Dilute* Calla 296, Dilute* Calla 602LF, Concentrated Calla 296, and Concentrated Calla 602LF.
**NOTE – Dilute means mix cleaning solution to manufacturer's recommended use concentration and heat to manufacturer's maximum recommended use temperature.*
- Cleaning solutions used in testing were:
Calla 296
Calla 602LF
- LHE Zn-Ni performs better than IVD and as well as Cad



Liquid/Solid Metal Embrittlement Testing



LHE Zn-Ni Plated and Cad Plated 300M Type 1a.1 Test Specimens in Self-Loading Bend Frames



Liquid/Solid Embrittlement Testing

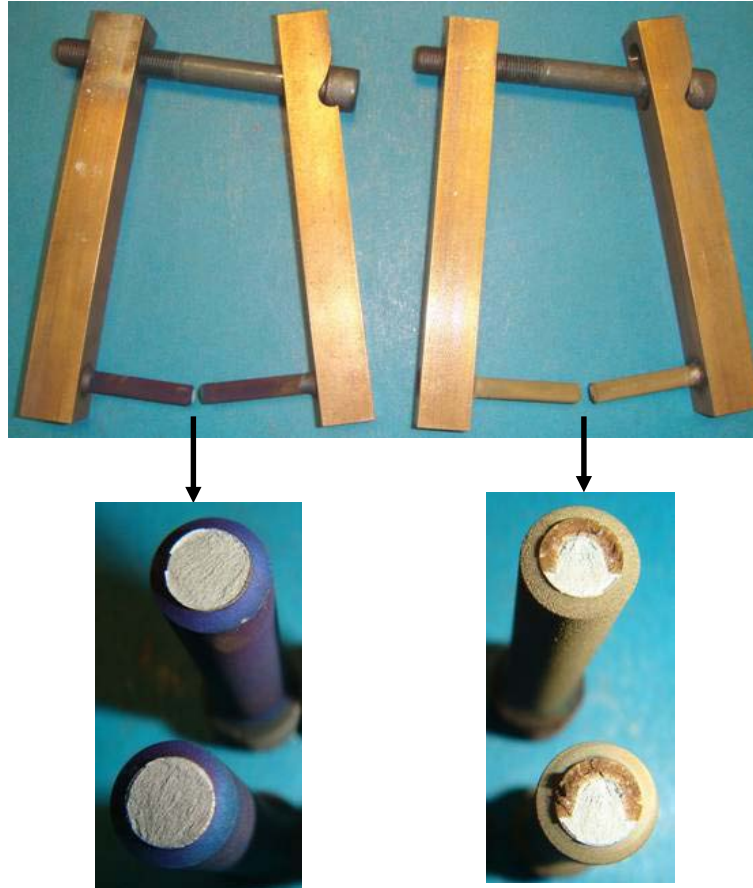


- Liquid and Solid Metal Embrittlement (LME and SME) occur when one metal, either as a liquid or solid, intrudes into the structure of another, potentially causing embrittlement in the base metal
- Melting points for the coating metals are as follows:
 - Cadmium ~610°F
 - Zinc ~787°F
 - Nickel ~2650°F

Temp/NFS	Material	Zn-Ni 200Hr	Cad 200Hr	Zn-Ni Step Load	Cad Step Load
600F/85%	300M	Pass	Fail	100% NFS	-N/A-
500F/85%	300M	Pass	Fail	100% NFS	87% NFS
400F/85%	300M	Pass	Fail	100% NFS	91% NFS
400F/75%	300M	Pass	Fail	100% NFS	81% NFS



Liquid/Solid Metal Embrittlement Testing



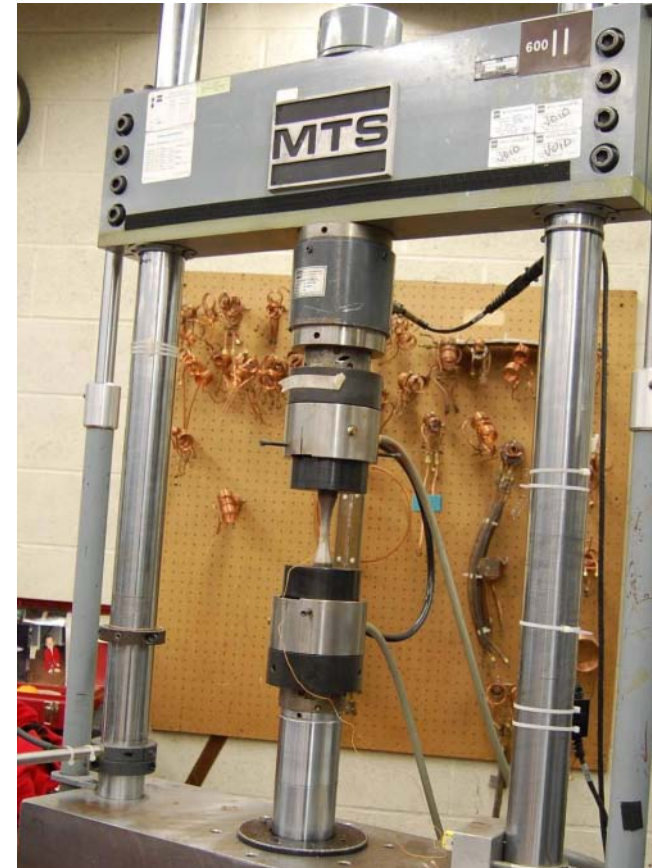
LHE Zn-Ni and Cad Type 1a.1 Specimens After ISL Test to Determine the NFS After Exposure to 400°F for 200 Hours



Fatigue Testing



- Phase II LHE Zn-Ni fatigue testing is an extension of Phase I work
- Phase II LHE Zn-Ni fatigue testing continues to broaden the data base and increase the statistical validity of the data
- Manufacturing of coupons and Fatigue Testing IAW ASTM E466
 - All coupons were plated per manufacture's plating solution limits

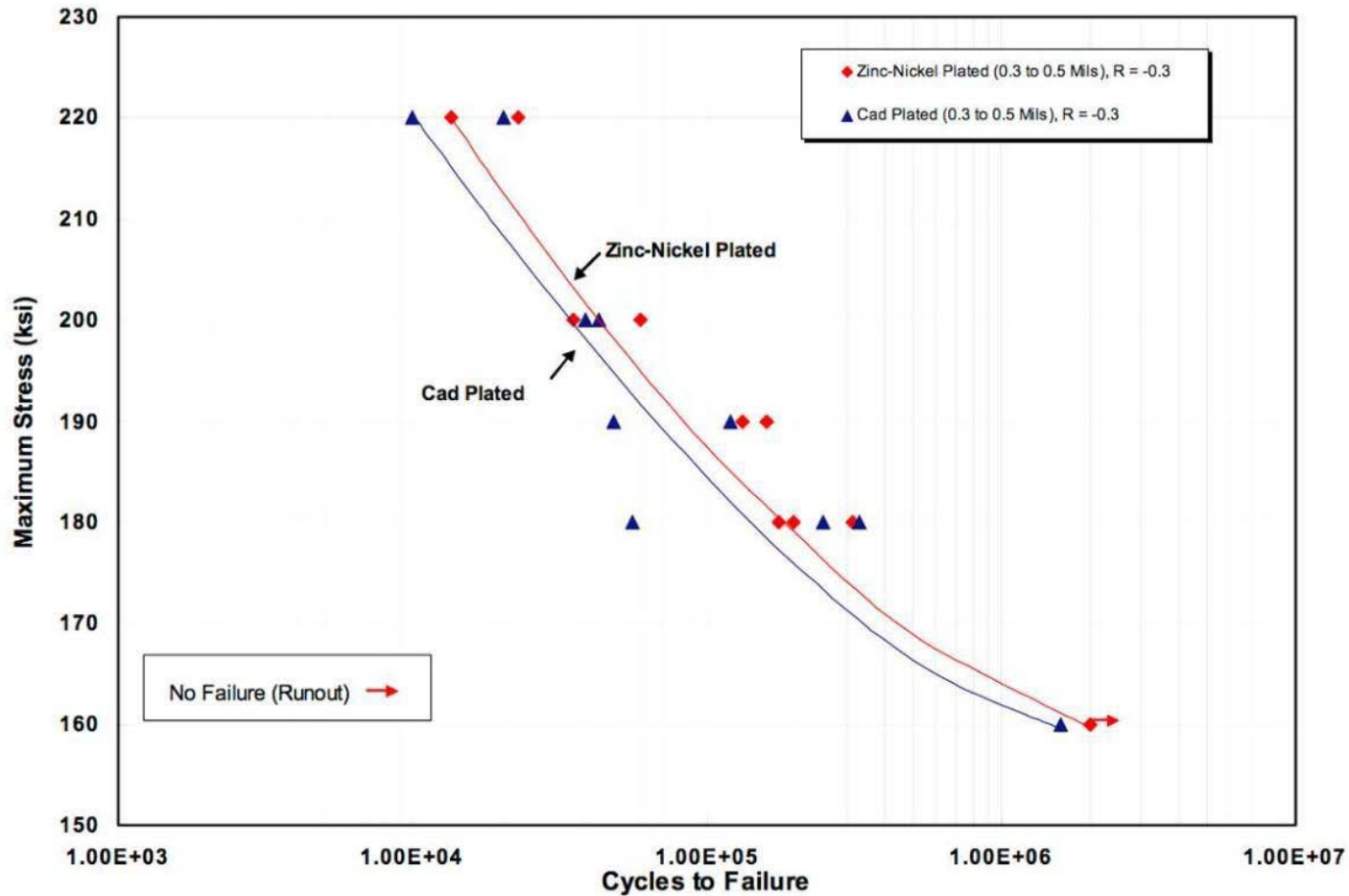




Phase I Fatigue Testing (Shotpeened Coupons)



C-17 P2 Program Fatigue Data (IZ-C17 with Hex conversion coating)





Phase II Fatigue Testing

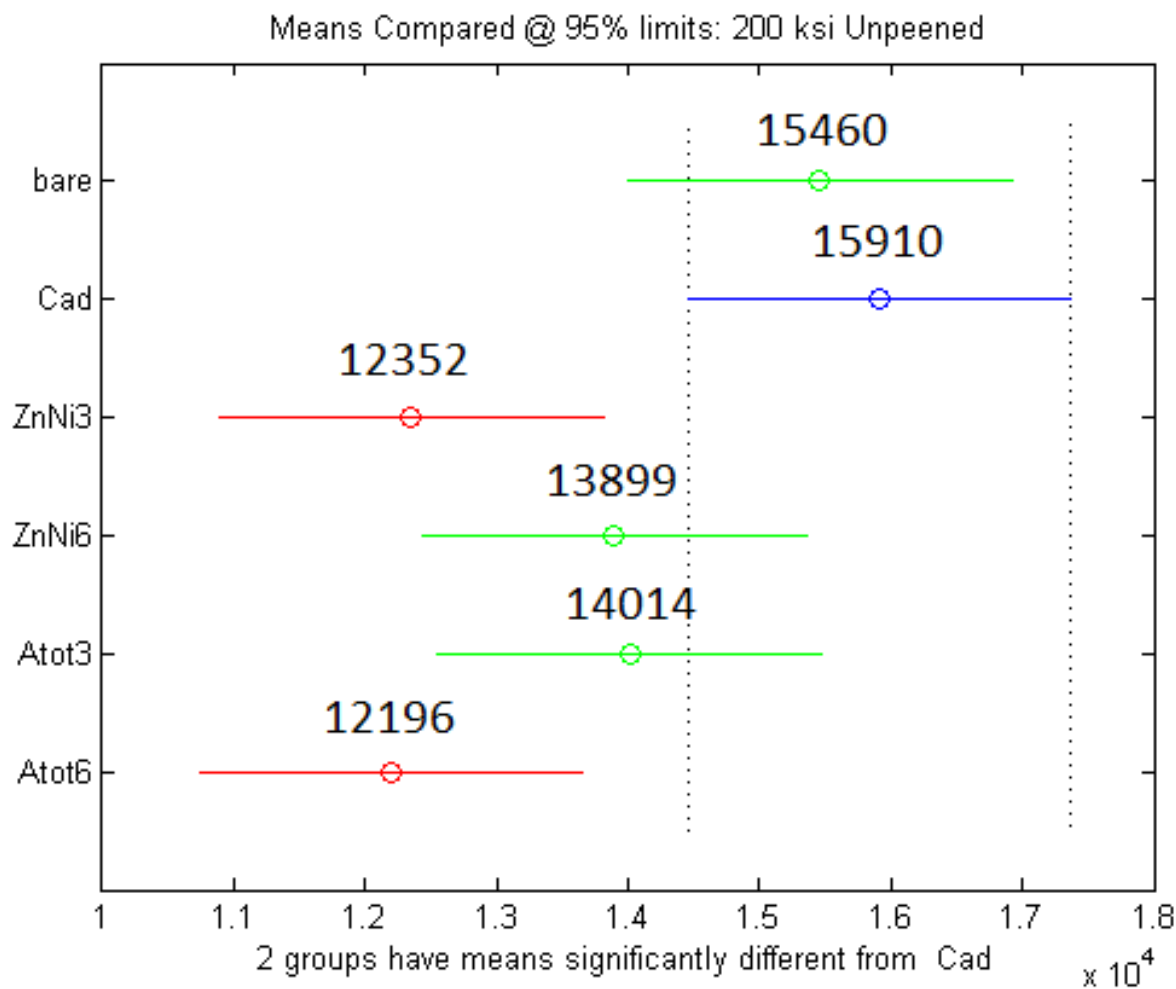
UnPeened Coupons	Stress Loads (KSI) R= -0.3			Total Quantity
	160	180	200	
Bare	5	5	5	15
Cad Plated	5	5	5	15
LHE Zn-Ni Plated Tri CC	5	5	5	15
LHE Zn-Ni Plated Hex CC	5	5	5	15
*Zn-Ni Plated Atotech Tri CC	5	5	5	15
Zn-Ni Plated Atotech Hex CC	5	5	5	15
Spares	5	5	5	15
Spares	5	5	5	15
Total Fatigue Coupons				120
* Bake before Tri CC				

Peened Coupons	Stress Loads (KSI) R= -0.3			Total Quantity
	160	180	200	
Bare	5	5	5	15
Cad Plated	5	5	5	15
LHE Zn-Ni Plated Tri CC	5	5	5	15
LHE Zn-Ni Plated Hex CC	5	5	5	15
*Zn-Ni Plated Atotech Tri CC	5	5	5	15
Zn-Ni Plated Atotech Hex CC	5	5	5	15
Spares	5	5	5	15
Spares	5	5	5	15
Total Fatigue Coupons				120
* Bake before Tri CC				



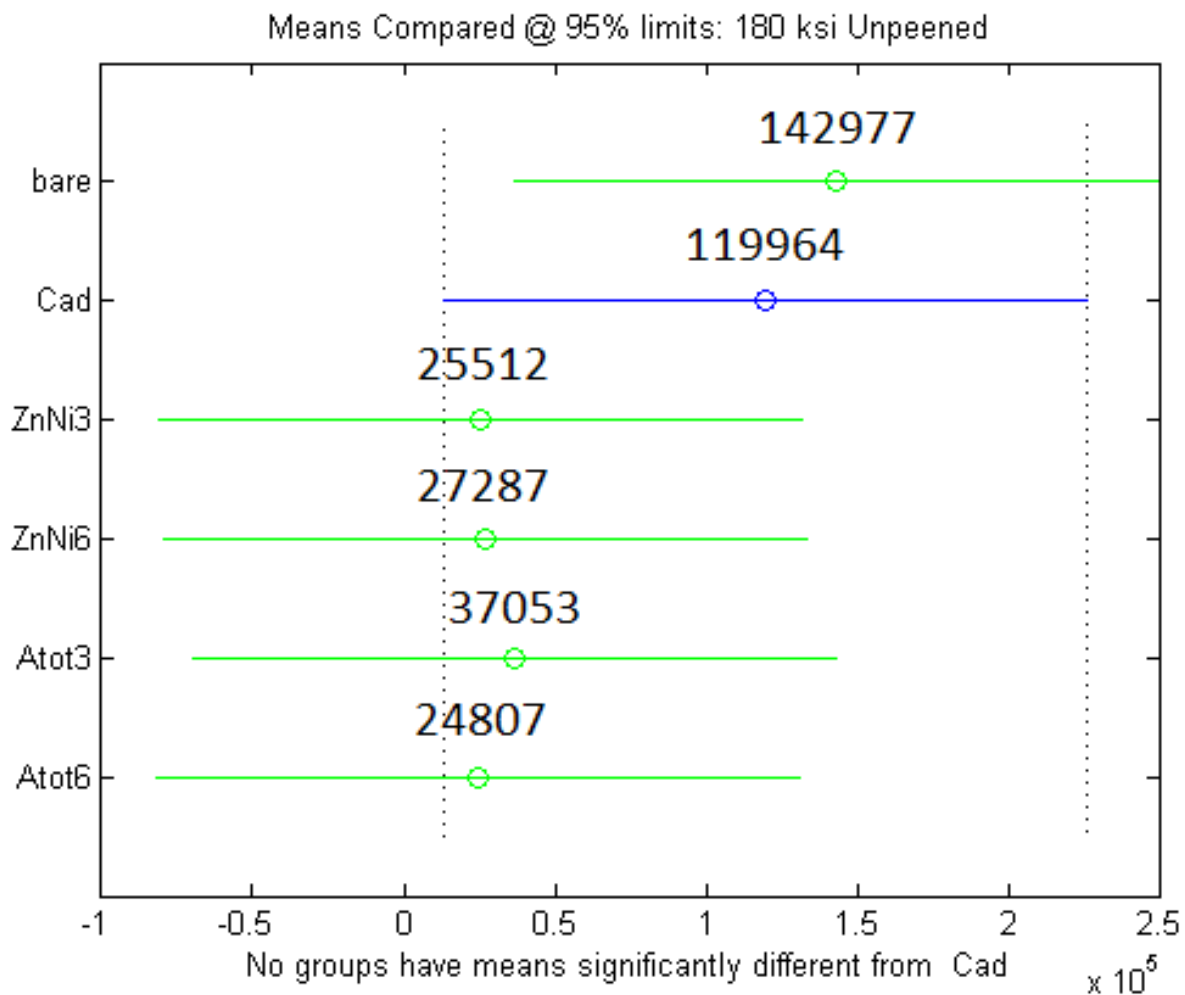


Phase II Fatigue Testing



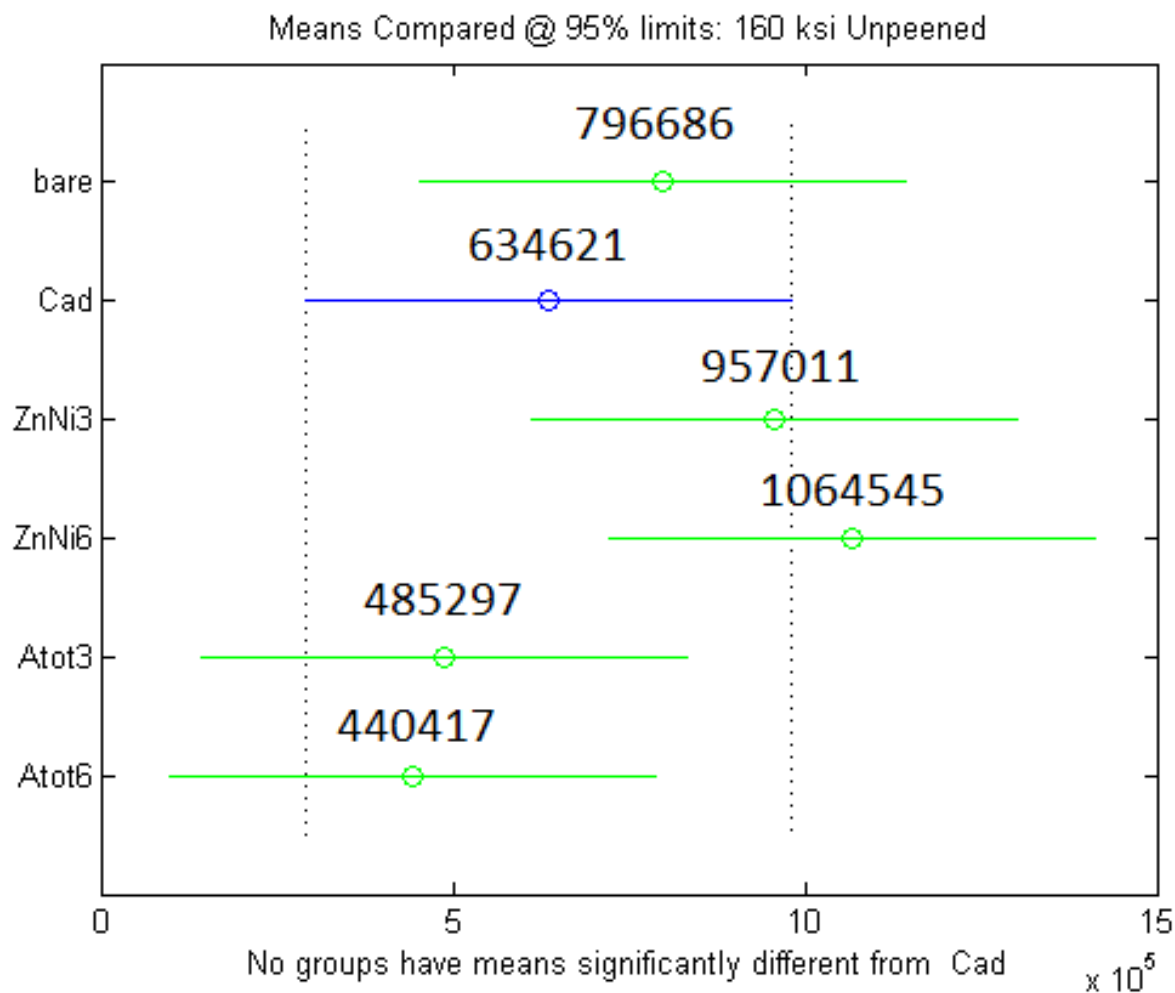


Phase II Fatigue Testing



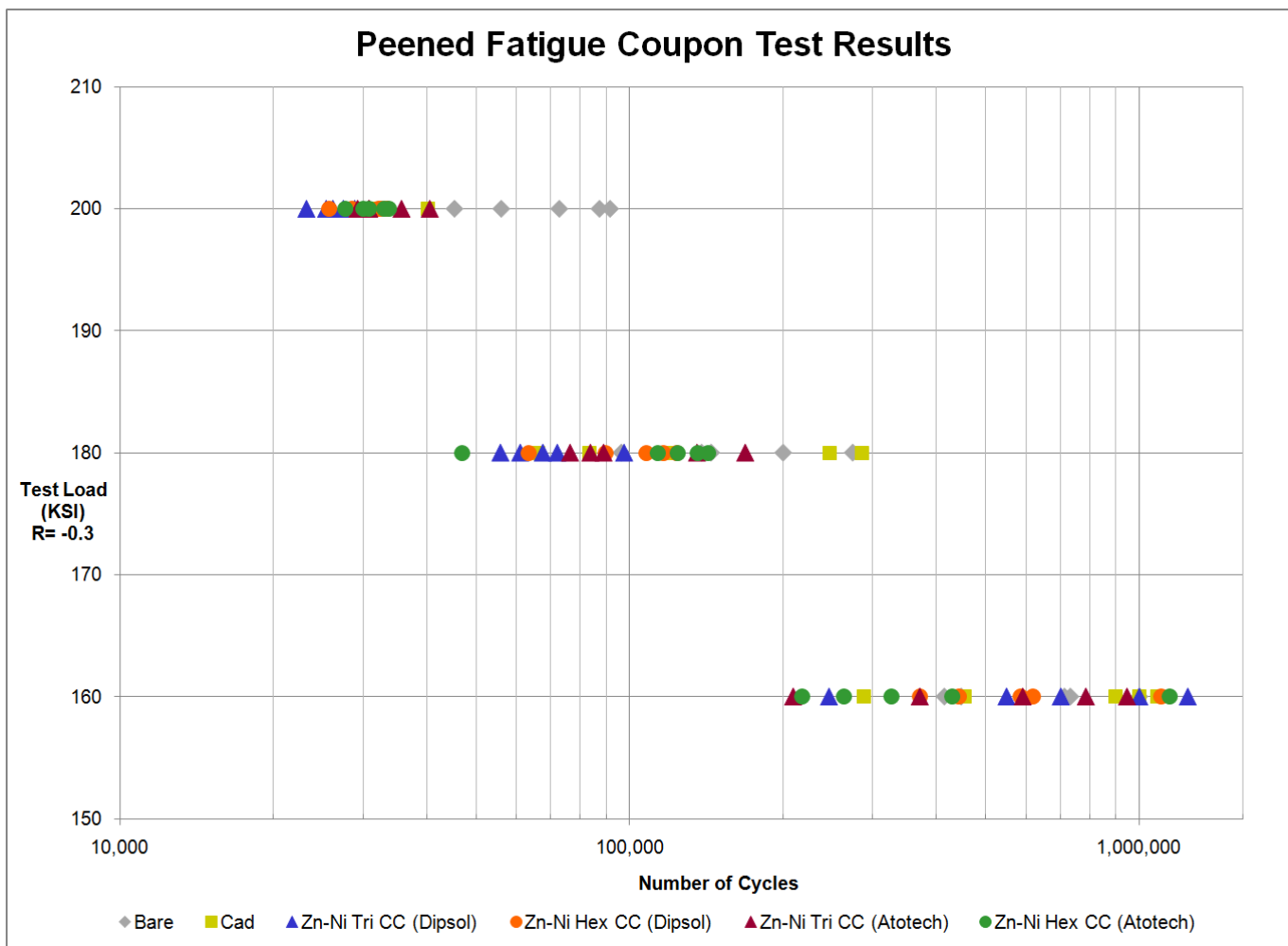


Phase II Fatigue Testing



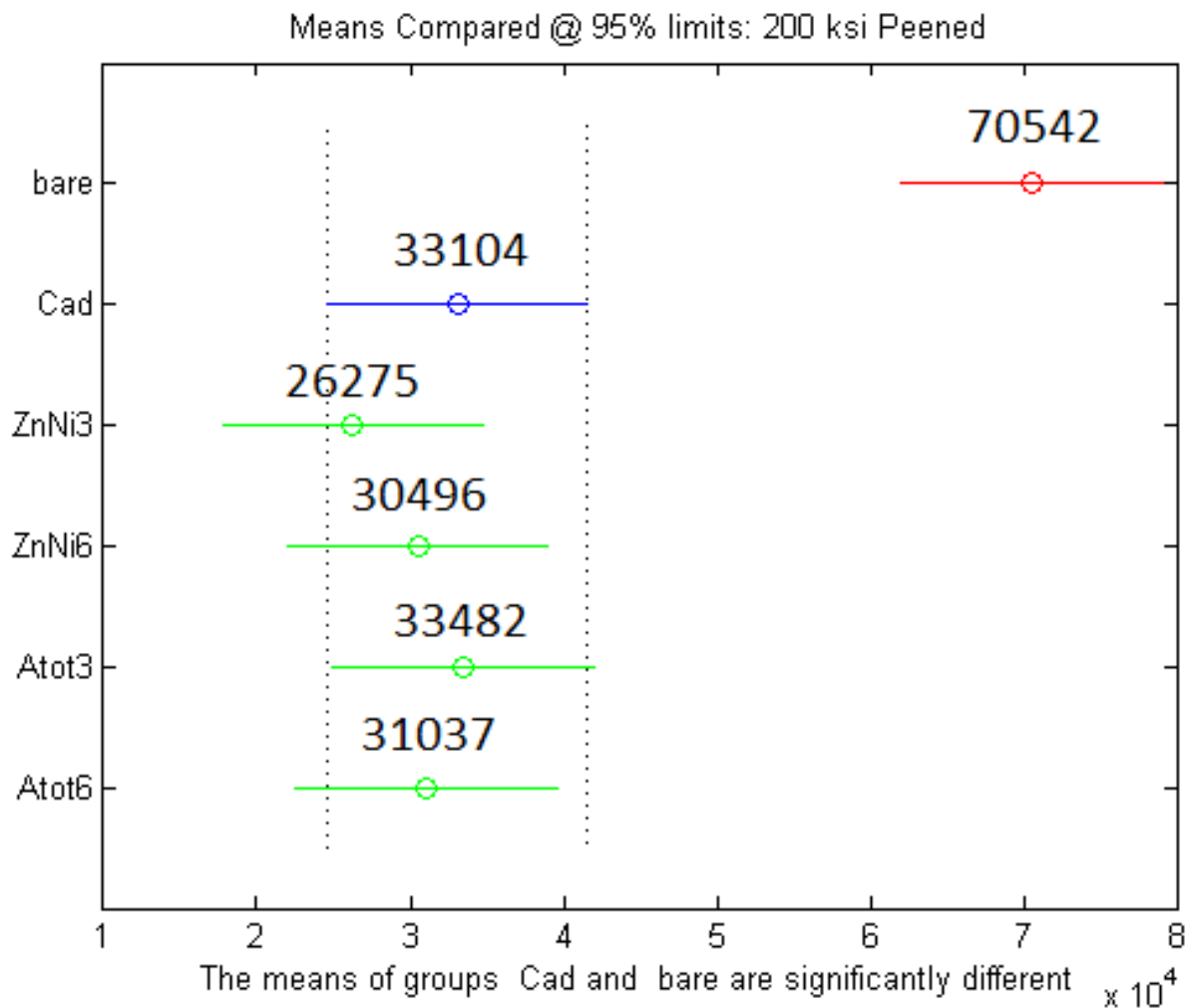


Phase II Fatigue Testing



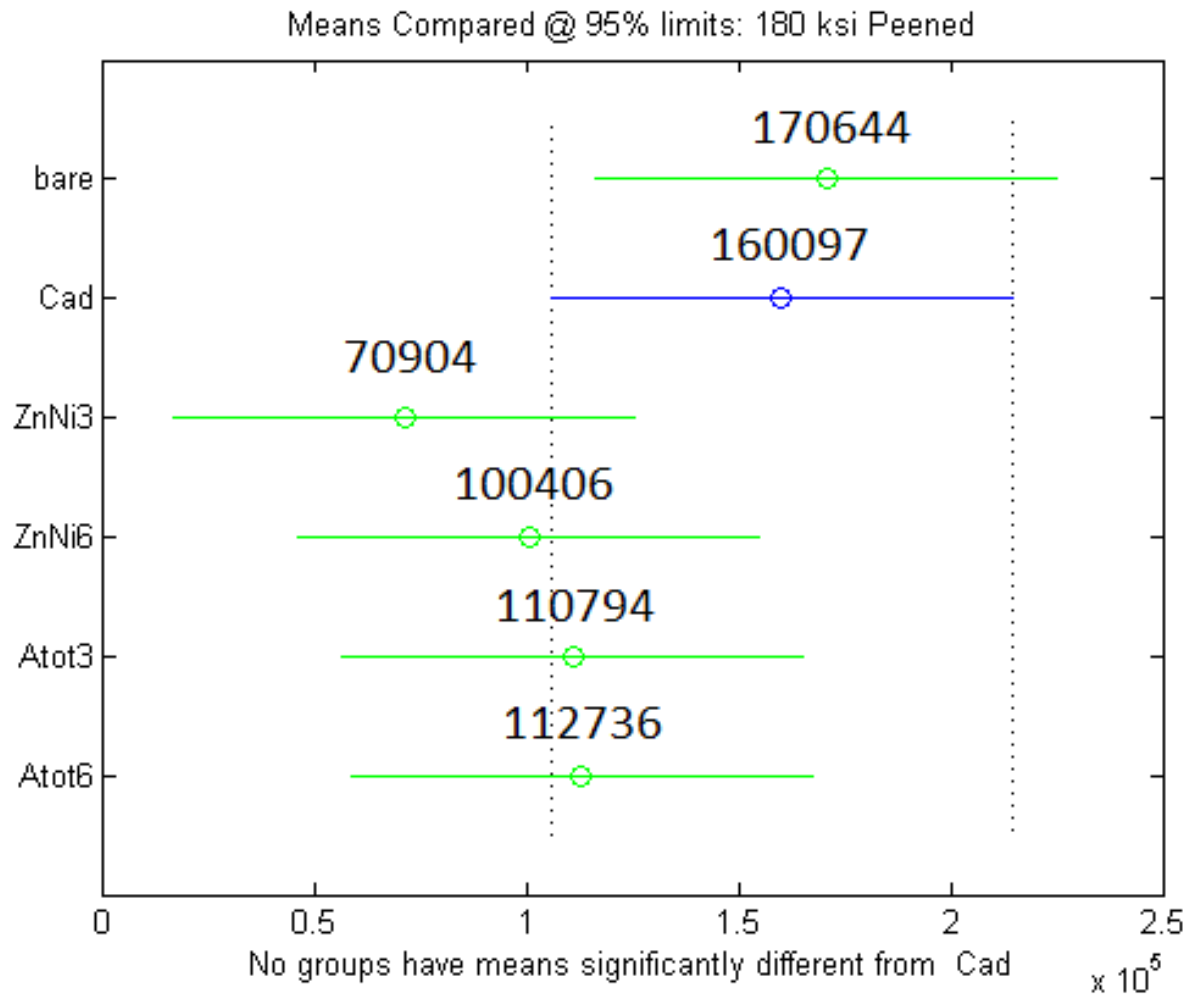


Phase II Fatigue Testing



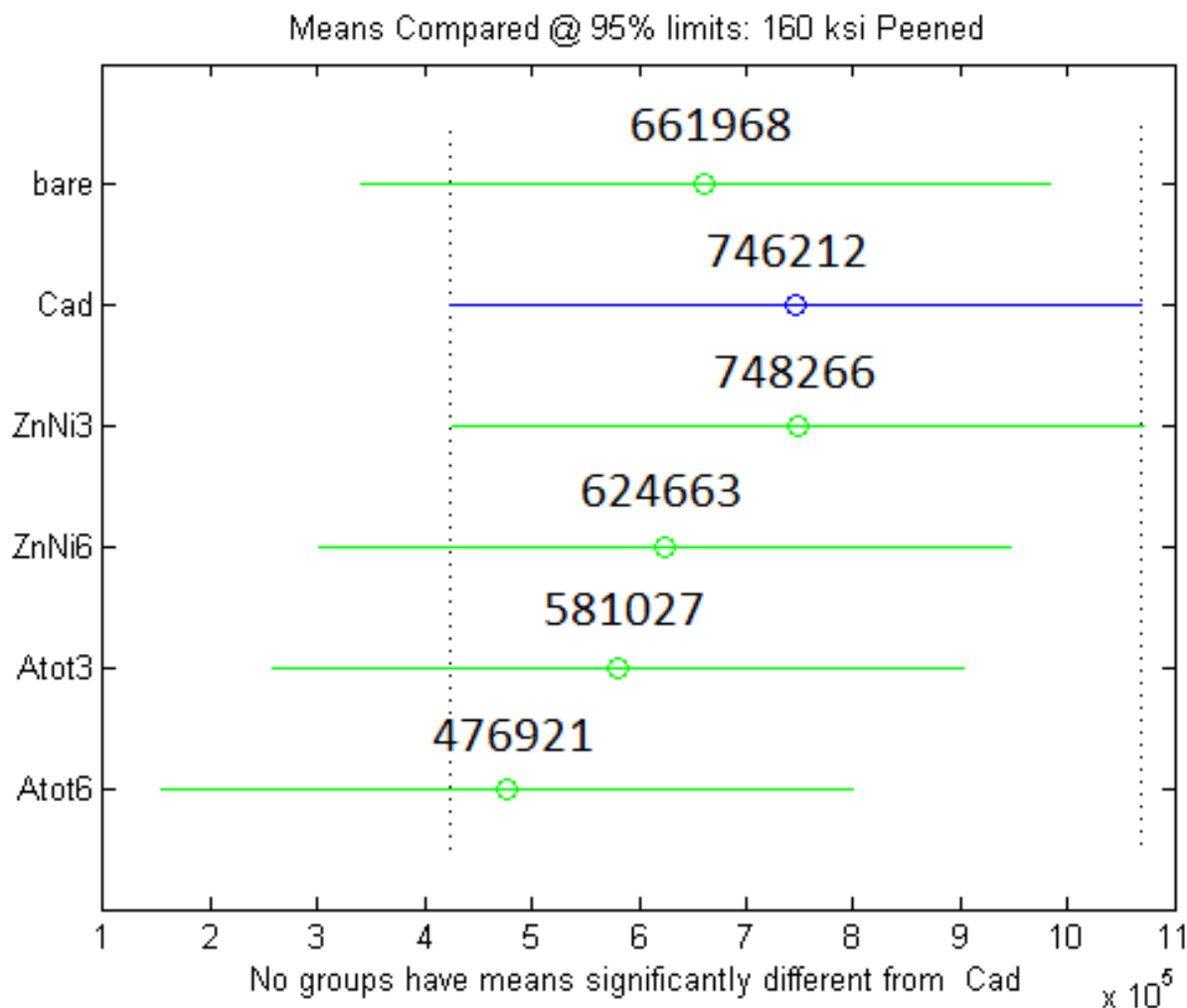


Phase II Fatigue Testing





Phase II Fatigue Testing





Corrosion Performance

- Corrosion tests were conducted on LHE Zn-Ni coupons with cadmium as the baseline
- Testing was also performed on both cadmium and LHE Zn-Ni coated coupons with a prime/paint topcoat after being scribed (See Table below). All test coupons were 4"x 6"x 0.040" 4130 steel sheet
- All testing was performed per ASTM B117
- Test specimens were both scribed and un-scribed



Corrosion Test Matrix

# of steel Panels	Plating	Scribed	Prime/Paint
3	LHE Zn-Ni	Yes	No
3	LHE Zn-Ni	No	No
3	Cd	Yes	No
3	Cd	No	No
3	LHE Zn-Ni	Yes	Yes
3	Cd	Yes	Yes



Corrosion Performance

Cadmium with Hexavalent Chrome Conversion Coating
Unscribed – ASTM B 117
Figure 3

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected



1000 hours

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

3000 hours

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

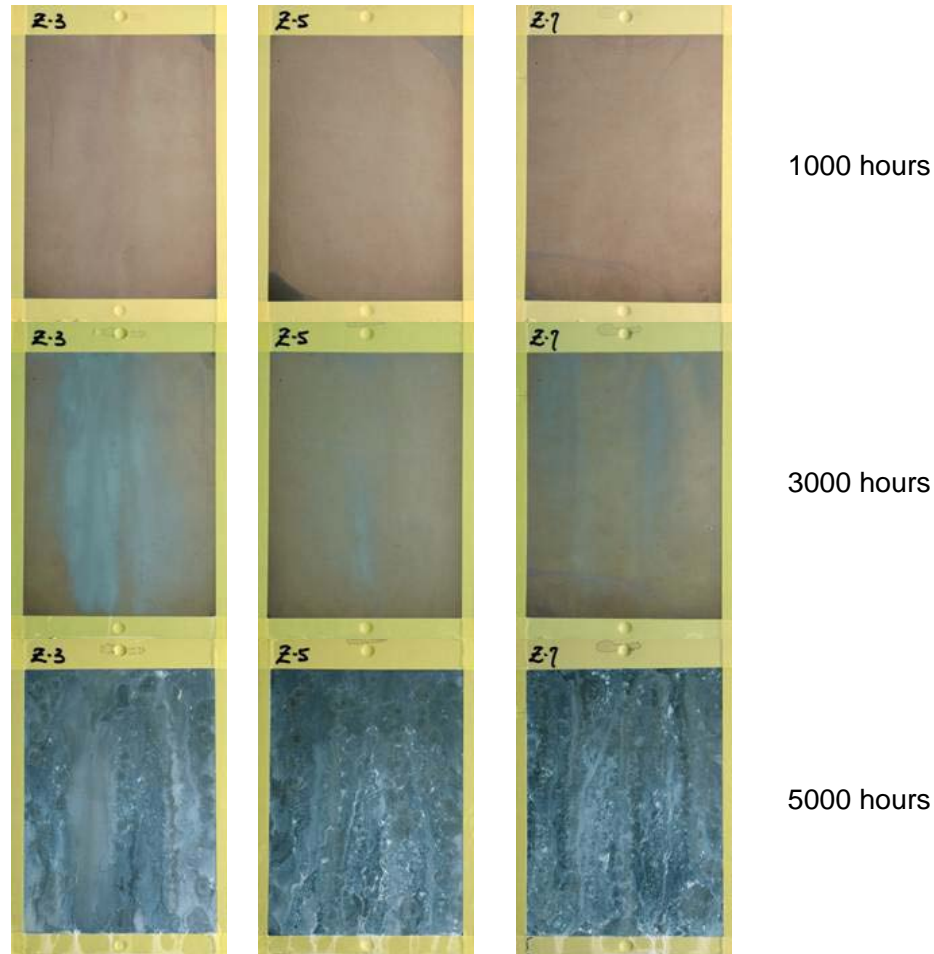
5000 hours

Cadmium Coatings – Phase II ASTM B 117 Panels @ Boeing Unscribed)



Corrosion Performance

IZ-C17+ Zn-Ni with Trivalent Chrome Conversion Coating
Unscribed – ASTM B 117
Figure 4



LHE Zinc Nickel Coatings – Phase II ASTM B 117 Panels @ Boeing (Unscribed)



Corrosion Performance

Cadmium with Hexavalent Chrome Conversion Coating
Scribed – ASTM B 117
Figure 5



Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

1000 hours

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

3000 hours

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

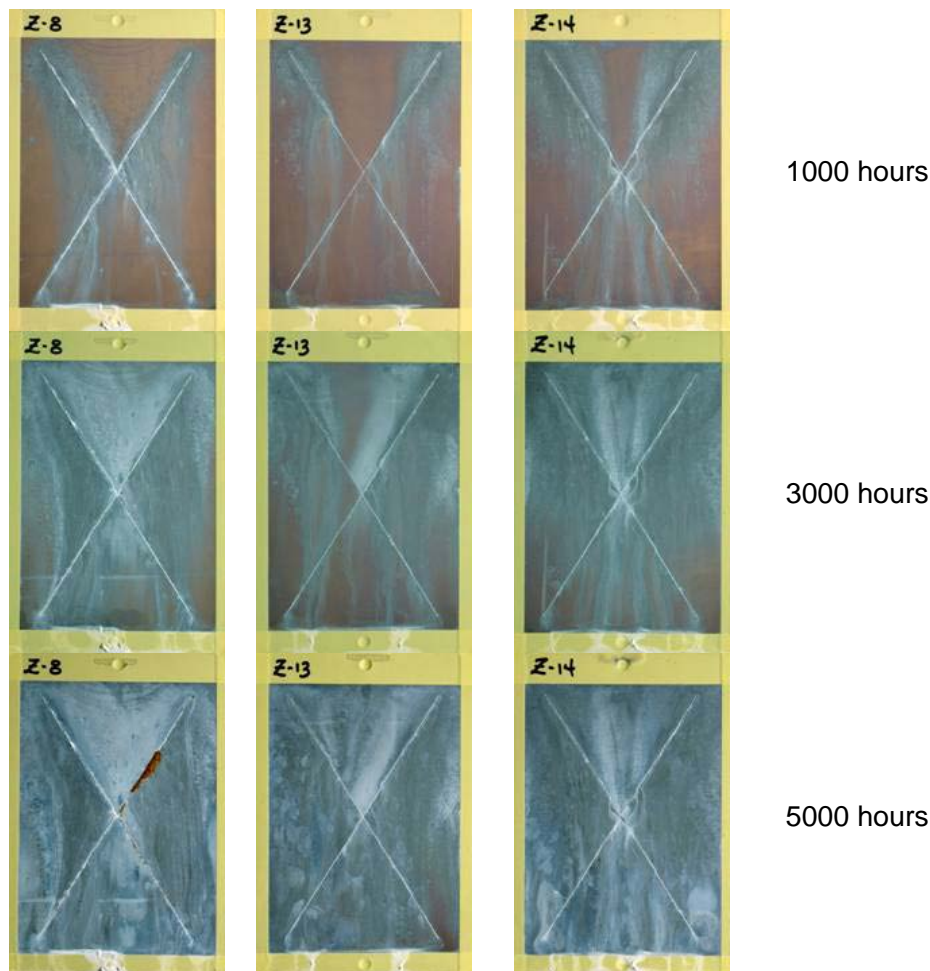
5000 hours

Cadmium Coatings – Phase II ASTM B 117 Panels @ Boeing (Scribed)



Corrosion Performance

IZ-C17+ Zn-Ni with Trivalent Chrome Conversion Coating
Scribed – ASTM B 117
Figure 6

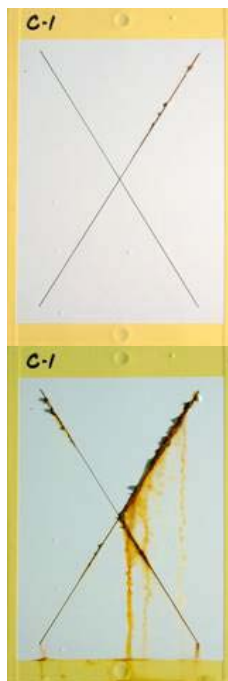


LHE Zinc Nickel Coatings – Phase II ASTM B 117 Panels @ Boeing (Scribed)



Corrosion Performance

Cadmium with Hexavalent Chrome Conversion Coating
Scribed Painted – ASTM B 117
Figure 9



Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

1000 hours

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

3000 hours

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

Test Panel
Removed From
Salt Spray Cabinet –
Excess Amount
of Red Rust
Detected

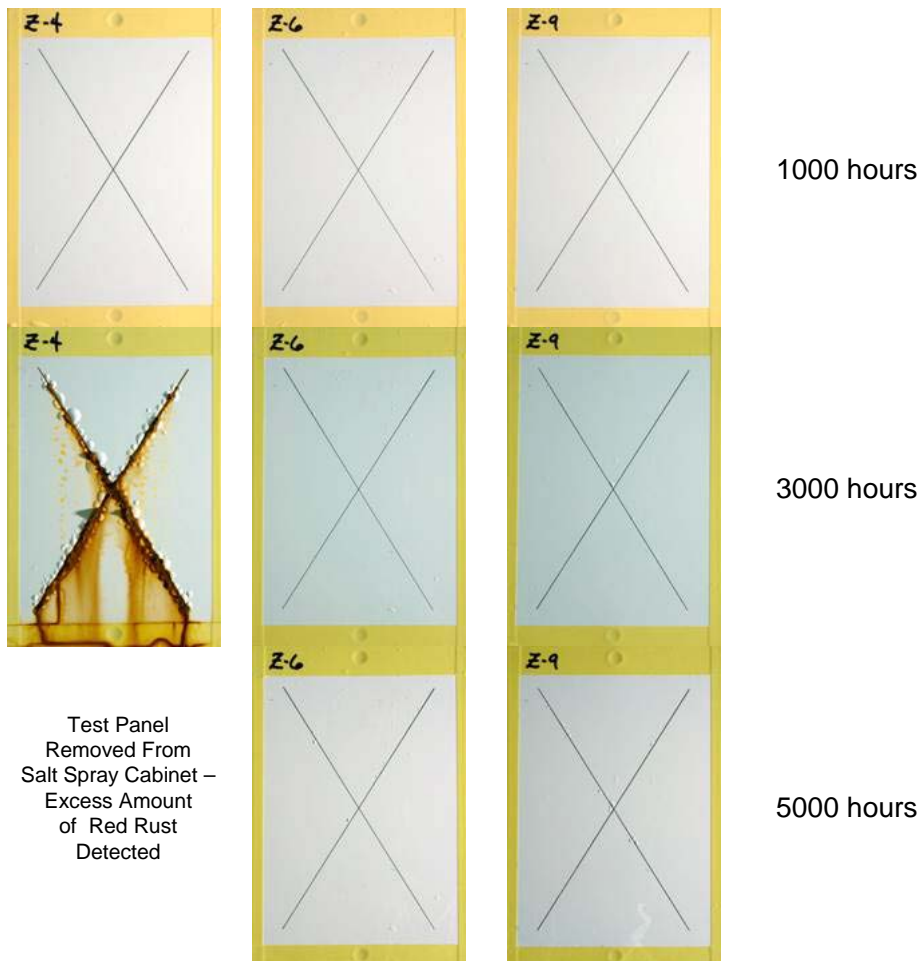
5000 hours

Cadmium Coatings – Phase II ASTM B 117 Panels @ Boeing (Painted/Scribed)



Corrosion Performance

IZ-C17+ Zn-Ni with Trivalent Chrome Conversion Coating
Scribed Painted – ASTM B 117
Figure 10



LHE Zinc Nickel Coatings – Phase II ASTM B 117 Panels @ Boeing (Painted/Scribed)



Brush Plating Repair



- In order for a brush LHE Zn-Ni plating to qualify it must pass the following tests:
 - Hydrogen Embrittlement (HE) testing per ASTM F519
 - Bend to break adhesion test per ASTM B571
 - Corrosion testing per ASTM B117
- SIFCO recommended procedures were used to plate several sets of HE type 1a.1 coupons, adhesion coupons, and corrosion coupons, using SIFCO 4018 No Bake LHE Zn-Ni brush plating solution
- Test Results Summary:
 - Passed HE testing
 - Passed adhesion testing on steel and LHE Zn-Ni plated steel
 - Corrosion test performance is excellent

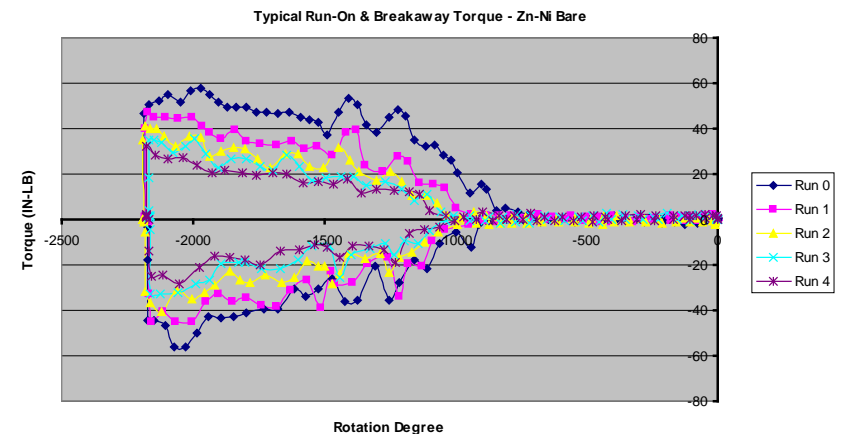
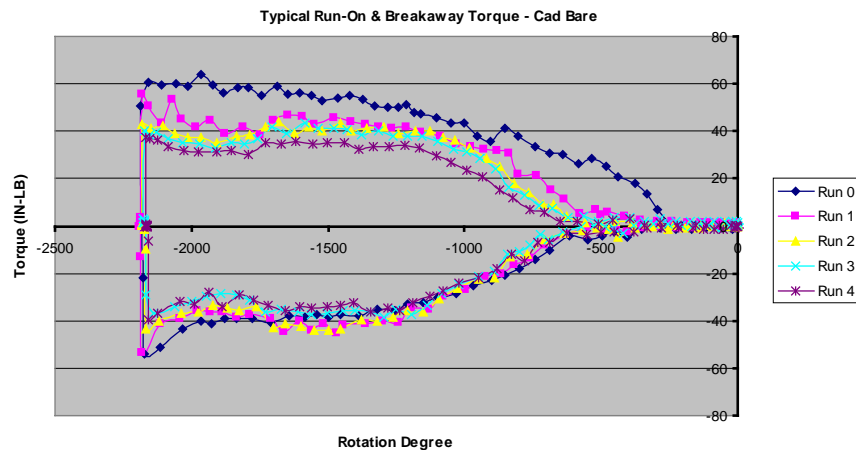




Torque Tension



- Robins AFB Cad plating replacement on threaded fastener and components
 - Typical chart for run on – break away test showing Cad vs. LHE Alkaline Zn-Ni

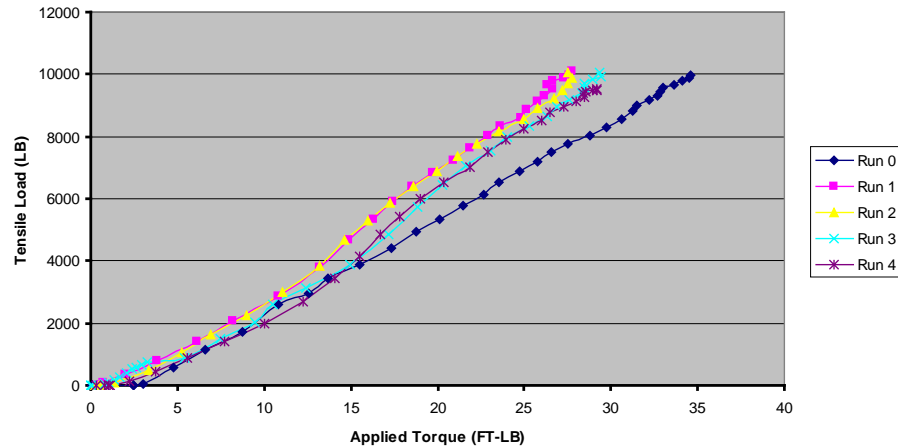




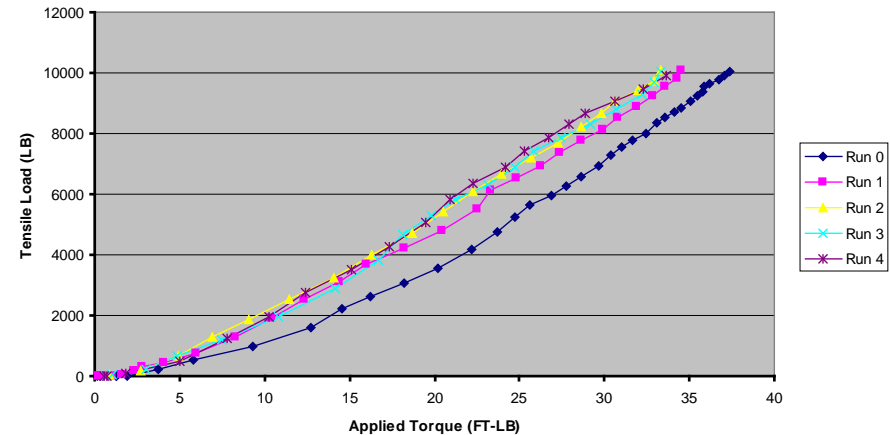
Torque Tension

- Robins AFB Cad plating replacement on threaded fastener and components
 - Typical chart for Torque Tension Test showing Cad vs. LHE Alkaline Zn-Ni with MIL-PRF-83483 Anti-seize grease lubricant

Typical Torque Tension - Cad w/ Anti-Seize Grease



Typical Torque Tension - Zn-Ni w/ Anti-Seize Grease





Back Up Slides: Zn-Ni Conformal Anode Fixtures

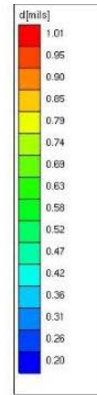
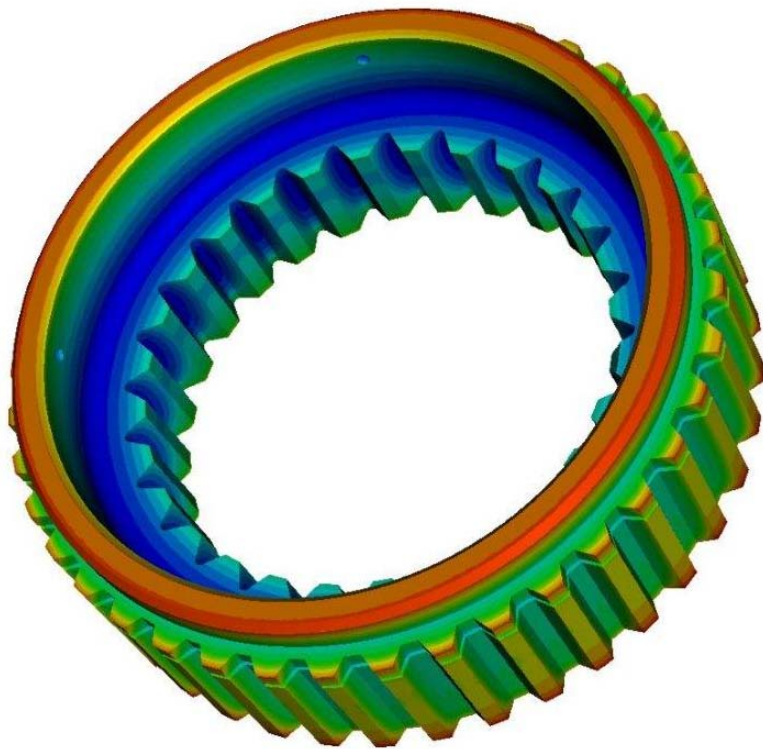


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STRENGTH AND HONOR



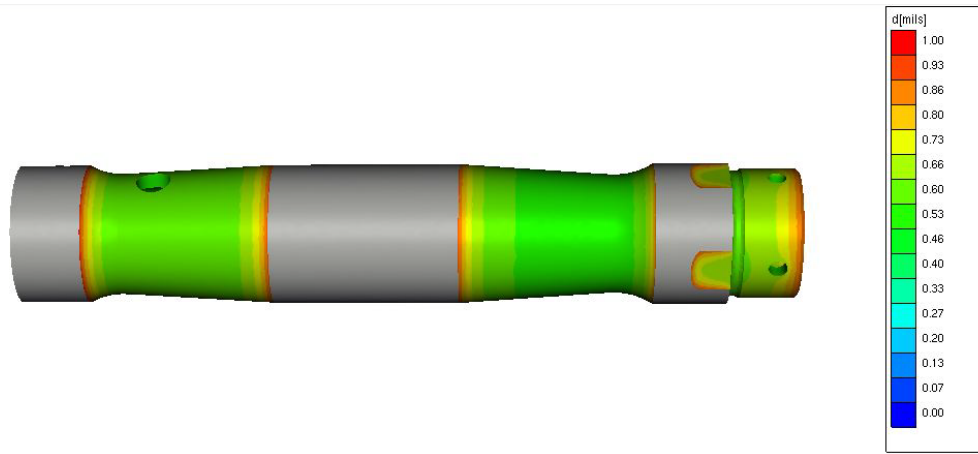
Phase III Effort Prototype Anode Design



MLG Rotation Collar



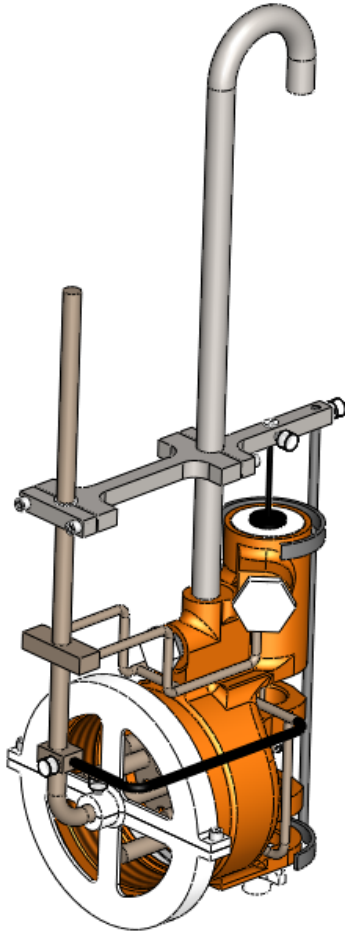
Phase III Effort Prototype Anode Design



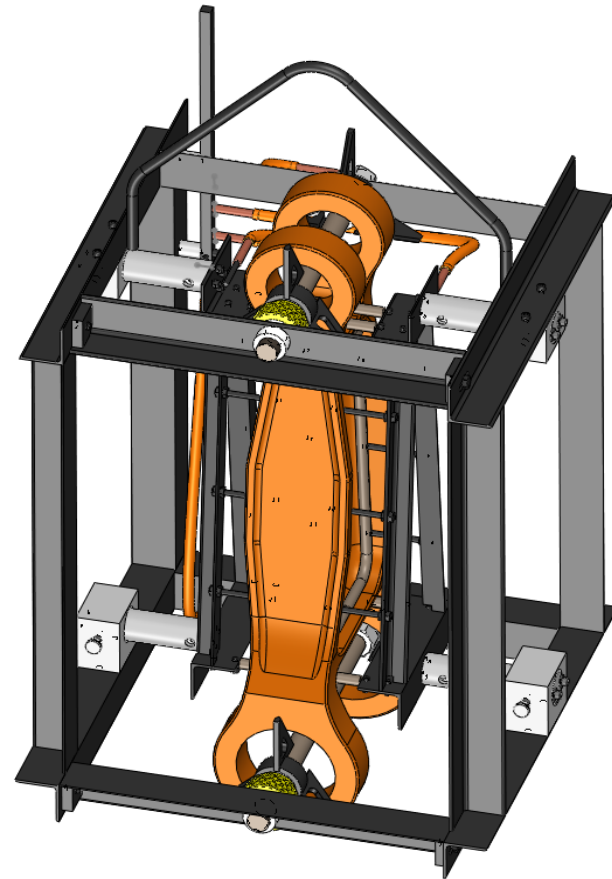
NLG Axle



LHE Zn-Ni Plating Conformal Anode and Fixture Models



NLG Outer Cylinder



MLG Lower Side Brace



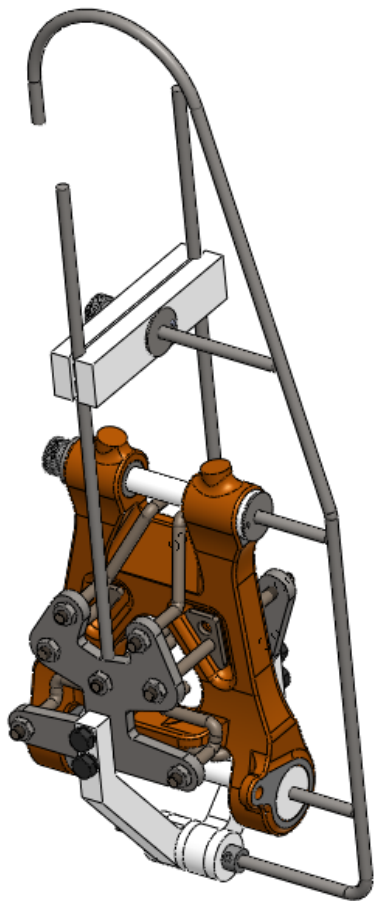
LHE Zn-Ni Conformal Anode and Fixture Models



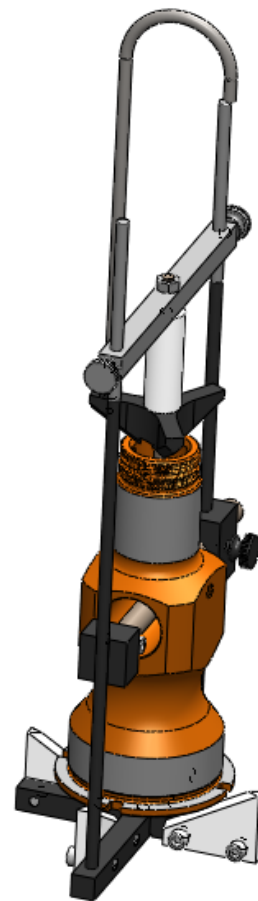
MLG Outer Cylinder



LHE Zn-Ni Plating Conformal Anode and Fixtures Models



MLG Torque Arm



MLG Pin



LHE Zn-Ni Completed Fixtures



MLG Lower Drag Brace



NLG Gimble Ring



LHE Zn-Ni Completed Fixture



NLG Inner Piston



Phase III Effort Prototype B-1 Bushing



Plating B-1 Bushings LHE Zn-Ni



Plated LHE Zn-Ni B-1 Bushings